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PROJECTION-TELEVISION RECEIVER

PART III. THE 25 kV ANODE VOLTAGE SUPPLY UNIT

by G. J. SIEZEN and F. KERKHOF.

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The power required for feeding the cathode-ray tube of a projection-television receiver amounts to only a few watts, at a direct voltage of the order of 20-30 kV. The method of supplying this power described here, in which a cascade rectifier is fed from a pulse generator, has several advantages over the more conventional method of stepping up and rectifying the A.C. mains voltage. The pulse generator consists of a coil taken up in the anode circuit of a pentode, the anode current of which is periodically and suddenly interrupted by a saw-tooth voltage on the control grid (frequency about 1000 c/s). The current interruption excites the oscillator circuit consisting of the inductance of the coil and its self-capacitance. The voltage peak across the coil can easily reach a value of the order of 10 kV. The desired direct voltage (in this cases 25 kV) is obtained with a rectifier, preferably consisting of a number of stages in cascade.

The cascade circuit is further analyzed. From the formulae derived it appears that with a non-controlled pulse generator a reasonable value of the internal resistance can only be obtained at a low efficiency. This difficulty has been overcome by applying to the pentode a control voltage derived from the peak voltage on the oscillatory circuit. The result is a low internal resistance in the range between no-load and full load, at a satisfactory efficiency, and a marked voltage drop when the load is excessive. The practical execution described here, employing a three-stage cascade rectifier, gives an output of 25 kV at 150 μA, and consumes about 11 W from a direct voltage source of 350 V. The internal resistance under no-load is about 5 megohms. The dimensions of the apparatus are only 18 cm × 10 cm × 15 cm (7″ × 4″ × 6″). In the oscillatory circuit good use has been made of "Ferroxcube".

Introduction

As explained in previous papers [1][2] (which will be referred to hereafter as I and II) on projection-television receivers, this method of reception provides a large-sized picture while at the same time the drawbacks attached to the use of large cathode-ray tubes for direct view are avoided. Thanks to the solution (described in the present series of articles) to the many problems arising with projection reception, the price of the receiving set has by no means increased in proportion to the size of the picture. The small cathode-ray tube, described in article II, allows a considerable saving compared with the tube which would be required for a direct vision picture of the same size as the projected picture. It is true that for the projection method an optical system is needed, but this need not contain any expensive components. As explained in article I, it has been found possible to keep the dimensions of the optical system very small, owing to a special positioning of the mirrors of which it is composed. This all helps to reduce the size of the cabinet and thus also the price.

Another component on which it is well worth economizing is the rectifier for feeding the cathode-ray tube with a voltage which in the present case amounts to 25 kV at a current of about 0.1 mA. Experience indicates that at such a high voltage a rectifier becomes cumbersome and heavy when the alternating voltage from the lighting mains is stepped up and rectified in the traditional manner. Moreover, in the event of a short-circuit the current would then become prohibitively high.

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[1] P. M. van Alphen and H. Rinia, Projection-television receiver, I. The optical system for the projection, Philips Techn. Rev. 10, 69-78, 1948 (No. 3).

[2] J. de Gier, Projection-television receiver, II. The cathode-ray tube, Philips Techn. Rev. 10, 97-104, 1948 (No. 4).

We shall now discuss a method whereby the rectifier is fed from a separate pulse generator working with a frequency of the order of 1000 c/s. This method has led to the construction of an inexpensive apparatus which is compact and has a good efficiency.

According to another method the saw-toothed time-base current for exciting the magnetic field for the horizontal deflection of the electron beam in the cathode-ray tube is used. This method is certainly economical but with such high voltages as 25 kV it has the drawback that the rectified voltage obtained is strongly dependent upon the amplitude of the horizontal deflection. Related to this is the fact that if the synchronisation should be lost the voltage would rise to impermissibly high values. Another drawback is that the load formed by the rectifier retards the fly-back of the electron beam. By employing the separate pulse generator described below these objections are avoided.

Still another method is known where the rectifier is fed from a separate high-frequency oscillator via a bandpass filter [3]). The most suitable frequency lies between 0.3 and 1.2 Mc/sec. This makes it necessary to provide good screening to prevent interference from these radio-frequencies. Furthermore, with this method the efficiency is low and the apparatus is rather bulky.

Principle and advantages of the pulse generator

The operation of the pulse generator is based upon the generation of voltage impulses when the current passing through a coil is interrupted. This interruption sets up an oscillation in the circuit formed by the inductance L of the coil with its self-capacitance C_p. If $I_{\max}$ is the strength of current at the moment of interruption then the peak value $V_{\max}$ reached by the oscillation voltage across the circuit is given approximately by

$$V_{\max} = I_{\max} \sqrt{\frac{L}{C_p}}\,, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

because the energy $^1/_2 L I^2_{\max}$ accumulated in the magnetic field of the coil at the moment that the current is interrupted is found a little later as $^1/_2 C_p V^2_{\max}$ in the electric field of the oscillator circuit (except for a small amount which owing to various losses has meanwhile been converted into heat).

Substituting in (1) for instance the following values: $I_{\max} = 120$ mA, $L = 0.5$ H and $C_p = 50$ pF, we find $V_{\max} = 12000$ V. This example shows that in this manner an alternating voltage with a peak value in the order of 10 kV can be obtained with values of L and C_p which can quite well be realized. Further, the current required can be supplied by an output pentode of moderate power with the coil in its anode circuit (*fig. 1*). The current can then be interrupted very efficiently by suddenly making the control grid voltage of the pentode so negative as to block the anode current.

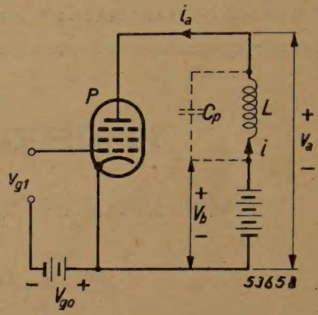

Fig. 1. Diagram of an pulse generator. L = self-inductance of a coil (with self-capacitance C_p) in the anode circuit of a pentode P.

A rectifier with a cascade circuit [4]) can be connected to the terminals of the coil, and thus a direct voltage can be obtained amounting to a multiple of the input voltage peak $V_{\max}$. We shall revert to this presently.

Although the shape of the curve of the anode current i_a prior to the interruption is of little consequence, a linear increase as seen in the curve for i_a in *fig. 2* has some advantages compared, for instance, with the case where I_a, being either zero or $I_{\max}$, would have a rectangular shape. With the shape of curve shown in fig. 2 the efficiency is better and there is less risk of the valve being overloaded.

Such a shape can easily be given to the anode current by using for the control grid voltage of the pentode an alternating voltage (v_{g1}, fig. 1) of a saw-tooth shape (supplied by a separate generator) combined with a suitable chosen negative bias V_{g0}. After the current is interrupted the control grid voltage must be kept sufficiently negative for some time to block the anode current in spite of the high positive anode voltage then arising (see fig. 2, curve for v_a).

If T is the time between two successive interruptions and a is the fraction of T during which anode current is flowing (see fig. 2) then the constant voltage difference ΔV_a at the coil during the interval aT is:

$$\Delta V_a = L\,\frac{\mathrm{d}i_a}{\mathrm{d}t} = \frac{L\,I_{\max}}{aT}\,,$$

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[3]) O. H. Schade, Radio-frequency operated high-voltage supplies for cathode-ray tubes, Proc. I.R.E. 31, 158-163, 1943.

[4]) See for instance Philips Techn. Rev. 1, 6-10, 1936.

and hence the interruption frequency $f_i = 1/T$ is

$$f_i = \frac{a \Delta V_a}{L\, I_{\max}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

For practical reasons the fraction a should preferably not be smaller than 0.25. The highest value of ΔV_a is equal to the difference between the direct voltage V_b supplying the anode circuit and the minimum anode voltage $V_{a\min}$ required to prevent too high a screen grid current. If this minimum anode voltage is, say, 50 V and V_b = 350 V, thus $(\Delta V_a)_{\max}$ = 300 V, with a = 0.25 and with the values of L (= 0.5 H) and $I_{\max}$ (= 120 mA) previously quoted, from (2) we find:

$$f_i = \frac{0.25 \times 300}{0.5 \times 0.120} = 1250 \text{ c/s.}$$

This frequency is so much higher than the mains frequency that the smoothing of the rectified voltage can be done much more easily than would be possible with frequencies of the same order as the mains frequency.

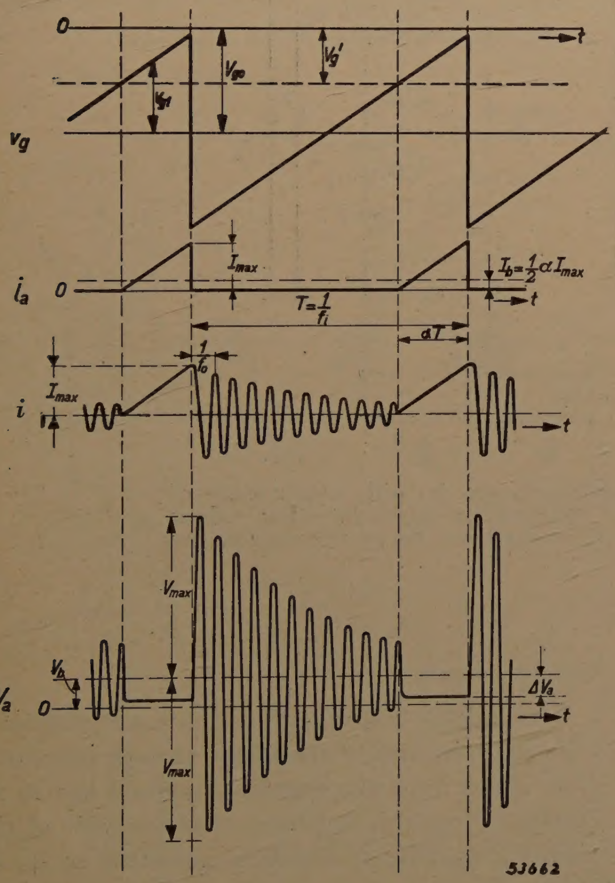

Fig. 2. Variation of voltages and currents with time t in the circuit of fig. 1. v_g = control grid voltage consisting of a bias V_{g0} and a saw-tooth voltage v_{g1} (period $T = 1/f_i$). During the time αT, the value of v_g exceeds that of V_g' and the anode current i_a is blocked. $I_{\max}$ = the value at which i_a is interrupted. I_b = mean value of i_a, i = current in the coil with the natural frequency f_0 of the circuit L-C_p, v_a = anode voltage of the pentode, V_b = D.C. supply voltage, ΔV_a = voltage drop in the coil while the anode current is flowing (interval αT), $V_{\max}$ = peak of the oscillatory voltage.

With L = 0.5 H and C_p = 50 pF the natural frequency f_0 of the oscillator circuit is 32000 c/s. This lies so far outside the range of radio-frequencies that there need be no fear of its giving rise to any interference.

Fig. 2 also gives the curves of the current i in the coil and of v_a as functions of the time t.

Before going into further details we would draw attention to the fact that the method described here allows of a very efficient control of the voltage, since in accordance with eq. (1) the voltage peak $V_{\max}$ (and thus also the direct voltage) is proportional to $I_{\max}$, the value of which is very easily regulated with the control grid bias. It is then only a small step further to make this control automatic by governing the bias with the peak voltage $V_{\max}$. In this way it is possible to obtain a highly constant direct voltage between certain load limits (in other words, the rectifier can be given a very low internal resistance), without the short-circuit current being much greater than the normal working current.

The rectifier

Theoretically $V_{\max}$ can be made any desired value; thus it could be chosen high enough to obtain the desired direct voltage (here 25 kV) with the aid of only one valve and one capacitor. There are, however, practical reasons why in our case preference is given to a lower value of $V_{\max}$, combined with a voltage multiplication by means of a cascade circuit of valves and capacitors. The reasons for this are the following:

In the first place it has to be considered that with pentodes of medium size the maximum permissible peak value of the anode voltage (here $V_b + V_{\max}$) is limited; with the type EL 38 for instance the limit is about 6 kV. One could try to keep the peak voltage below this limit by connecting the anode to a tap on the coil, which then acts as a step-up autotransformer. If one were to go so far as to render voltage multiplication unnecessary, either the coil would have to be very large or the anode current would have to be raised to a level exceeding the limit fixed for the EL 38.

The energy that the transformer has to supply with every pulse is fixed. It is $\frac{1}{2} L' I_{\max}^2$, where L' is the self-inductance of the primary of the coil. If the step-up ratio is chosen so high as to be able to dispense with voltage multiplication in the rectifier, then the two extreme possibilities are the following. One, L' can be chosen equal to the value L yielding according to eq. (1) the desired high voltage peak $V_{\max}$. If this is done, because of the high step-up ratio, the whole coil is much larger than the primary part; or two, the inductance L'' of the whole coil can be chosen equal to L, but then L' is much smaller than L, so that according to eq. (1) the current $I_{\max}$ would have to be considerably increased.

In the execution chosen the voltage is stepped up only slightly (1:1.4), so that voltage multiplication is still necessary.

In the second place, as far as the valves are concerned we must remember that in a cascade circuit with n stages the voltage across each of the n valves is roughly only $2/n$ of the direct voltage V_h supplied. The employment of n valves each calculated for a voltage $2V_h/n$ may be preferable to using one valve that would have to carry the voltage $2V_h$.

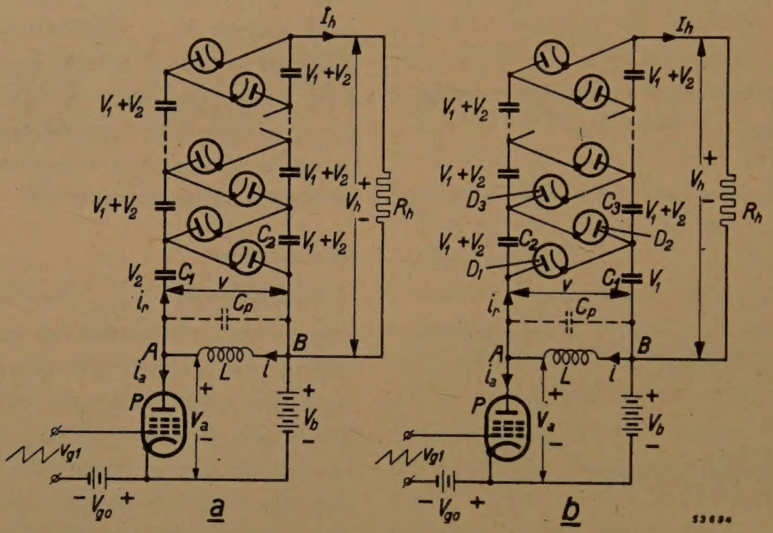

Fig. 3. Cascade rectifier, connected to a pulse generator, (*a*) with even number of stages, (*b*) with odd number of stages. V_h = direct voltage output, R_h = load resistor through which the direct current I_h flows; i_r = current taken up by the rectifier. For V_1 and V_2 see fig. 4.

A third point of consideration is the dimensions of the coil, which greatly increase with the value required of the peak voltage $V_{\max}$.

The following will make this clear: From eq. (1) it is easily deduced that

$$V_{\max} = B\sqrt{\frac{Q\,(l+\mu_r d)}{\mu_0\,\mu_r\,C_p}}\,, \quad . \; . \; . \quad (3a)$$

where B represents the magnetic induction, Q the cross section of the magnetic circuit, l the average length of the lines of force in the ferromagnetic core (of which μ_r is the relative permeability), d is the size of the air gap and μ_0 is the permeability of the vacuum ($= 4\pi\cdot10^{-7}$ H/m)[5]. For different coils having the same value B, with the size of the air gap so chosen in each case as to give the maximum L, it is found that with all these coils the most favourable air gap forms approximately the same fraction λ of the length l, so that eq. (3a) becomes

$$V_{\max} = B\sqrt{\frac{Ql\,(1+\lambda\mu_r)}{\mu_0\mu_r C_p}} \quad . \; . \; . \; . \; . \; . \; . \quad (3b)$$

Thus the volume Ql of the ferromagnetic core is roughly proportional to $V_{\max}^2$. (The self-capacitance C_p is assumed to be constant, but actually it increases with the size of the coil, so that the volume will increase with the voltage to a still greater extent than $V_{\max}^2$.)

Thus, although there are a number of facts in favour of keeping the voltage $V_{\max}$ fairly low, it would not be rational to use a very large number of stages in cascade. Consequently a compromise has to be sought. In order to do so we shall consider the cascade circuit somewhat more closely.

Cascade circuit

In a cascade circuit one of the input terminals coincides with one of the direct current terminals. Now in our case the negative terminal has to be earthed. From this it follows that that side of the circuit L-C_p (fig. 1) which is connected to + V_b has to be the negative pole. This leads to the arrangements indicated in *figs. 3a* and *b*, for an even and an odd number respectively of stages n in cascade. (It will be seen that small differences arise in the formulae applying in these two cases, both of which can in principle be used. Therefore one must differentiate between an even number of n and an odd number of n.)

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[5] Here we are using Giorgi units (see for instance Philips Techn. Rev. 10, 79-86, 1948 (No. 3). $V_{\max}$ is therefore expressed in V, B in Wb/m², Q in m², l and d in m, C_p in F, and μ_r is the permeability in relation to that of vacuum.

To begin with we shall deal briefly with the variation of the voltages and currents with time; we shall confine our considerations to the steady state and introduce some simplifying assumptions which sufficiently approximate practical conditions. We shall ignore the internal resistance of the valves and assume that the capacitors in the cascade circuit have a capacitance that is not only large compared with C_p but also large enough to allow the ripple voltage on these capacitors to be ignored. Thus across each of the capacitors there is a pure direct voltage.

From fig. 3 it follows that immediately after every interruption of the anode current the voltage across the circuit L-C_p has a polarity where A is positive with respect to B.

We shall confine ourselves for the time being to the case where n is an *odd* number (fig. 3*b*). As soon as v has reached the value V_1 of the direct voltage across the capacitor C_1, the first diode (D_1) becomes conductive and thus the capacitance C_1 comes to lie in parallel to the much smaller capacitance C_p. The circuit voltage v cannot then rise to the peak value V_m which it would reach if there were no rectifier, but remains limited to the value V_1 (*fig. 4*, curve v). As soon as the current ceases to flow through the diode — that is to say at the end of the first rectifying interval t_{r1} —, v begins to drop, according to a cosine function with the initial value V_1.

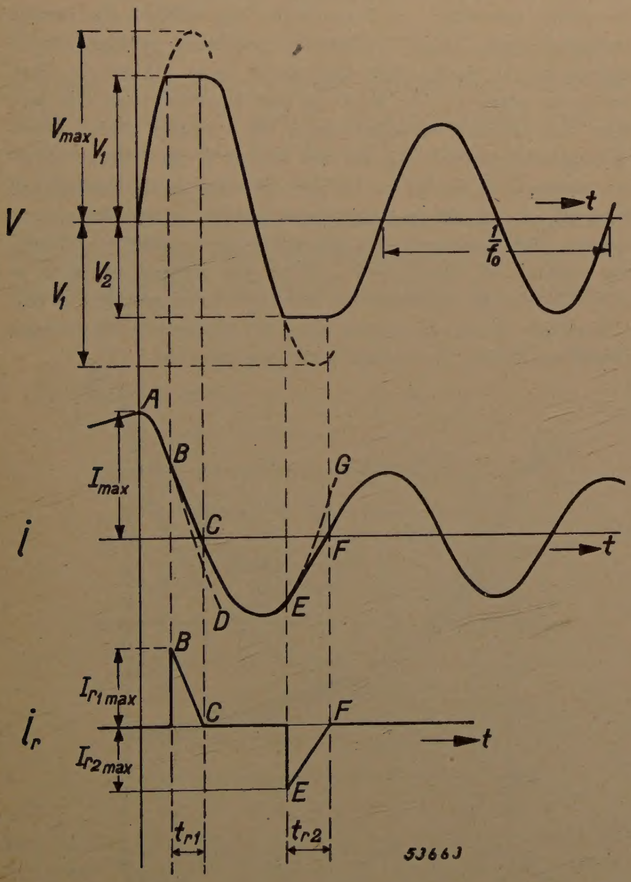

Fig. 4. Voltage and current curves as functions of t in the circuit according to fig. 3*b*. v = voltage at the coil, i = current through the coil, i_r = current taken up by the rectifying circuit. V_1, V_2 = amplitude of the first and second voltage peaks respectively; t_{r1}, t_{r2} = duration of the first and second rectifying intervals respectively.

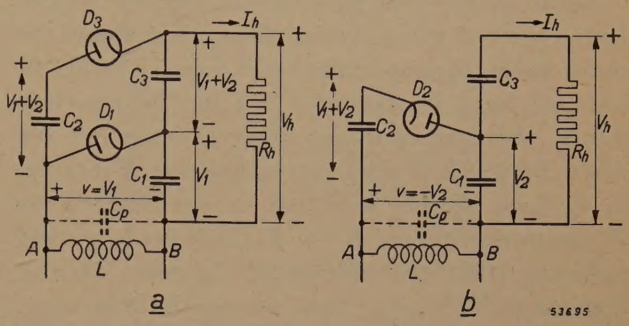

Fig. 5. These diagrams correspond to fig. 3*b* for $n = 3$. (*a*) is the situation during the first rectifying interval ($v = V_1$) when the diode D_2 (not shown) is non-conducting. (*b*) is for the second rectifying interval ($v = -V_2$); the diodes D_1 and D_3 which are then non-conducting have been omitted.

As soon as v has become sufficiently negative, or in other words as soon as the circuit voltage, assisted by the voltage V_1 on the first capacitor, has reached the value existing on the second capacitor C_2, current is able to flow through the second diode (D_2 in fig. 3*b* and also in *fig. 5b*, which corresponds to fig. 3*b* for the case where $n = 3$ but in which the temporarily non-conducting diodes D_1 and D_3 have been omitted). From that moment onwards v is again kept constant (now at a value which we shall indicate by $-V_2$, see curve v in fig. 4), because the large capacitance formed by C_1 and C_2 in series is shunted across C_p. From fig. 5*b* we now read that the voltage at C_2 has the value $V_1 + V_2$. The second rectifying interval, t_{r2}, lasts until the current has fallen to zero.

Owing to the damping, the succeeding peaks of v are in absolute value smaller than V_2; consequently they cannot contribute towards the rectification. For every period T there are, therefore, only the two rectifying intervals mentioned.

During these intervals, as we have seen, the voltage on the circuit is constant, that is to say the current through C_p is then zero and the current i through the coil is a linear function of time. Owing to the continuity conditions, which oppose current surges through a coil and voltage surges on a capacitor, during the first interval the variation of i must follow the tangent BC to the damped cosine line ABD in the point B corresponding to the beginning of the interval (fig. 4, curve i). Similarly, the variation in current during the second interval follows the tangent EF to the damped sine curve CEG. Since we are considering that part of the period T in which the anode current $i_a = 0$, during the rectifiying intervals the current i in the coil is equal to the current i_r (fig. 4, curve i_r) taken up by the cascade circuit.

In the foregoing we have only considered the first and second of the n diodes. Now what about the trend of the current in the other valves? In fig. *5a* we again have the case of $n = 3$ for the situation during the first rectifying interval, omitting the diode D_2 which is then non-conducting. From fig. *5b* we have already seen that C_2 was charged via D_2 up to the voltage $V_1 + V_2$. It is easily proved indirectly that the voltage at C_3 must likewise amount to $V_1 + V_2$. Now, during the first rectifying interval the cascade connection comprises not only the current path D_1-C_1 between the input terminals A and B but also a second path, C_2-D_3-C_3-C_1 shunted across the first one. Along this second path the voltages on C_2 and C_3 neutralize each other, so that the position is as if the diodes D_3 and D_1 were connected direct in parallel. Thus the current I_r is equally divided between the two branches.

This reasoning can of course be extended for odd numbers $n > 3$. It then leads to the deduction that the voltage $V_1 + V_2$ is present on all the cascade capacitors (except for the first, where the voltage is V_1), and that the n valves can be divided into two groups: one group of n_1 valves (in fig. *3b* drawn more to the left) functioning simultaneously in the first rectifying interval, and a group of n_2 valves (more to the right in fig. *3b*) which function during the second rectifying interval. It can easily be worked out that $n_1 = (n + 1)/2$, $n_2 = (n - 1)/2$.

Obviously a similar reasoning can be followed for an *even* number n (fig. *3a*). Here it will suffice to state that the conclusion derived above holds also for n = even, the only differences being that the voltage at the first capacitor is not V_1 but V_2 and that each of the simultaneously functioning groups of valves consists of $n/2$ valves.

Some important characteristics

After these qualitative considerations of the cascade circuit, we shall proceed to deal with some important characteristics. We shall first consider the external characteristic, namely the direct voltage output V_h as a function of $1/R_h$ (R_h = load resistance). From this characteristic we shall later on deduce the internal resistance.

From figs *3a* and *b* it is found that the direct voltage V_h across the output terminals is:

$$V_h = n_1 V_1 + n_2 V_2,$$

regardless whether n is an odd or and even number. At no-load apparently $V_1 = V_2 = V_{\max}$, so that for the ratio y of V_h to the no-load voltage V_{h0} we can write:

$$y = \frac{V_h}{V_{h0}} = \frac{V_h}{n V_{\max}} = \frac{n_1}{n}\frac{V_1}{V_{\max}} + \frac{n_2}{n}\frac{V_2}{V_{\max}}. \quad (4)$$

The unknown quantities V_1 and V_2 can be eliminated with the aid of the two energy equations

$$\tfrac{1}{2} C_p \left(V_{\max}^2 - V_1^2\right) = n_1 V_1 V_h T/R_h, \quad . \quad . \quad (5)$$

$$\tfrac{1}{2} C_p \left(V_1^2 - V_2^2\right) = n_2 V_2 V_h T/R_h \quad . \quad . \quad (6)$$

Eq. (5) expresses that the energy given off by the oscillatory circuit during the first rectifying interval is used to replace that part of the charge that is drawn from n_1 cascade capacitors by the external load in one period T. At the moment of interruption of the anode current the energy in the electromagnetic field amounts to $\tfrac{1}{2}LI_{\max}^2$. Disregarding circuit losses, we may write for this $\tfrac{1}{2}C_p V_{\max}^2$. At the end of the first rectifying interval $i = 0$ and $v = V_1$, so that the circuit energy is then $\tfrac{1}{2}C_p V_1^2$. Thus the left-hand member of (5) represents the energy that the circuit loses during the first rectifying interval. The load current I_h arises from the fact that the cascade capacitors give off a charge which flows through the resistor R_h. In one period T the charge flowing through R_h is $I_h T = V_h T/R_h$. During the first rectifying interval, n_1 of the n capacitors receive a supplementary charge. The source of this charge is the oscillatory circuit, the voltage of which is V_1. Thus the energy supplied is $n_1 V_1 V_h T/R_h$, as indicated by the right-hand member of (5).

Similarly it can be shown that (6) represents the energy transition during the second rectifying interval.

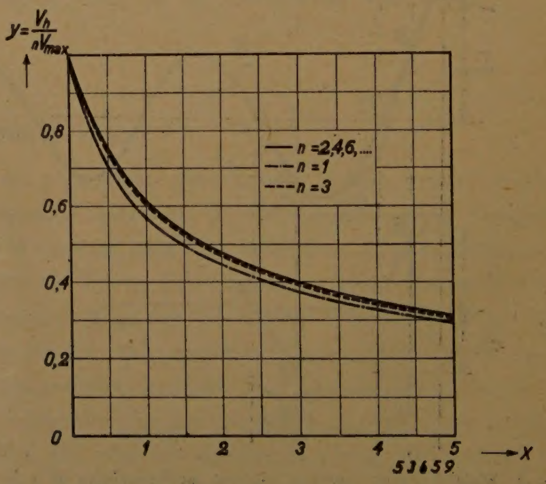

Fig. 6. The general external characteristic $y = f(x)$ where y is a measure for the direct voltage V_h and x is inversely proportional to the load resistance R_h. The upper curve applies for even values n, the lower one for $n = 1$, the middle one for $n = 3$.

We shall not go further into the elimination of V_1 and V_2 from (4), (5) and (6) here, because these calculations have already been published elsewhere 6). The result is given in *fig. 6*, in which $y = V_h/V_{h0}$ is represented as a function of a quantity x proportional to $1/R_h$ which occurs in the calculation and is defined by

$$x = \frac{n^2}{C_p} \frac{T}{R_h} \cdot \ldots \ldots \ldots \quad (7)$$

It is seen that one curve is found for all even values of n and a number of slightly deviating curves each for one odd value of n. The larger the odd number n with respect to unity, the closer the solution approaches that for an even value of n.

To give an idea of the order of size of x, we use the numerical values already applied: $T = 1/1250$ sec. and $C_p = 50$ pF, to which, when V_h and I_h amount respectively to 25 kV and 100 μA, can be added $R_h = 250$ megohms. Then $x = 0.064$ for $n = 1$; 0.26 for $n = 2$; 0.58 for $n = 3$.

As may be seen in fig. 6, in this range the curves fall steeply, which is already an indication that the internal resistance will be high. We shall find confirmation of this presently.

Besides $V_h = \mathrm{f}(x)$, there are some other graphs of importance, namely those representing the trend of the voltages V_1 and V_2 each separately with x, and also the graphs for the peak values $I_{r1\max}$ and $I_{r2\max}$ of the pulses going to make up i_r (see fig. 4, curve i_r). With the aid of the foregoing considerations these characteristics can be derived from the eqs (4)-(7). The results are given in *figs. 7* and *8*, fig. 7 giving $V_1/V_{\max}$, and $V_2/V_{\max}$, and fig. 8 $I_{r1\max}/I_{\max}$ and $I_{r2\max}/I_{\max}$, as functions of x, respectively for n = even, $n = 1$ and $n = 3$.

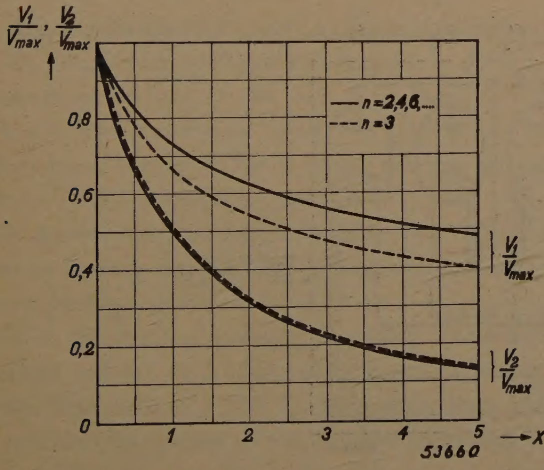

Fig. 7. The ratio of the first and second voltage peaks V_1 and V_2 to $V_{\max}$ as a function of x. Fully drawn curves apply to an even number n and the dotted curves to $n = 3$.

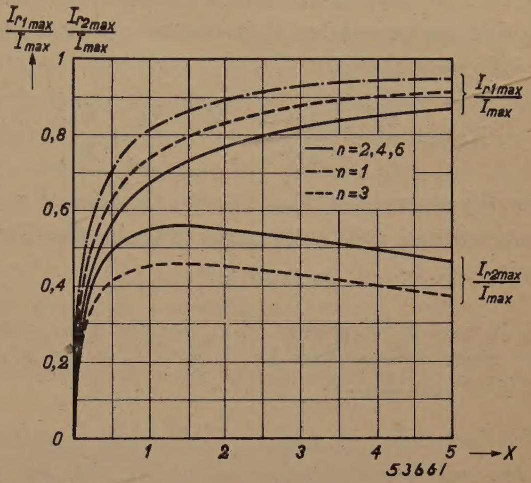

Fig. 8. The first and second current peaks $I_{r1\max}$ and $I_{r2\max}$ of the current I_r in the rectifying circuit, both in relation to $I_{\max}$, plotted as a function of x for n = even, $n = 1$ and $n = 3$.

From fig. 7 it is to be seen that as the load increases V_2 drops much more quickly than V_1, a phenomenon which will be referred to later.

Fig. 8 is of importance in choosing the number of stages n. It has been deduced above that the peak currents $I_{r1\max}$ and $I_{r2\max}$ are distributed respectively among n_1 and n_2 valves connected in parallel. Thus the peak current in each of the n_1 valves is found by dividing $I_{r1\max}$ by n_1, whilst $I_{r2\max}/n_2$ is the peak current in each of the other n_2 valves. If an even number of n is chosen, that is to say $n_1 = n_2 = n/2$ then according to fig. 8 the peak current in the n_1 valves is greater than that in the second group. If, on the other hand, $n = 3$, thus $n_1 = 2$ and $n_2 = 1$, the peak currents of the three valves are approximately equal, which obviously is the most economical. (Moreover, the choice of $n = 3$ is favourable also in other respects, such as the dimensioning of the coil in the anode circuit of the pentode).

Internal resistance and automatic control

With the aid of eq. (7) the internal resistance $R_i = -\mathrm{d}V_h/\mathrm{d}I_h$ can be expressed in the form

$$R_i = \frac{-n^2 y'}{y + x\,y'} \cdot \frac{T}{C_p},$$

where $y' = \mathrm{d}y/\mathrm{d}x$.

Here we shall pay particular attention to the value R_{i0} of the internal resistance when the load is very small, thus the slope of the characteristic $V_h = \mathrm{f}(i_h)$ in its initial point on the V_h-axis. This initial value (which from now on for the sake of

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6) G. J. Siezen and F. Kerkhof, Home projection-television, Part II. Pulse-type high-voltage supply, Proc. I.R.E. **36**, 401-407, 1948 (No. 3), in particular pages 404 and 405.

simplicity we shall call "the" internal resistance) is found by putting $x = 0$ in the last formula and substituting for y and y' the corresponding values that can be calculated from the eqs (4)-(7). We than find an expression that can be converted into the following form:

$$R_{i_0} = \frac{n_1^2 + n_1 n_2 + n_2^2}{2\,n^2} \cdot \frac{V_b}{\Delta V_a} \cdot \frac{V_{h0}^2}{W_b}. \qquad (8)$$

Here W_b represents the energy supplied by the direct voltage source (voltage V_b) in the anode circuit (fig. 1).

W_b is equal to the product of V_b and the mean value I_b of the anode current. From fig. 2, curve i_a, it can be read that $I_b = {}^1/_2\ a\ I_{\max}$.

The factor $(n_1^2 + n_1 n_2 + n_2^2)/2n^2$ has a value of ${}^3/_8$ for an even number n whilst for an odd number n it varies from ${}^1/_2$ for $n = 1$ to ${}^3/_8$ for $n = \infty$.

From (8) we see that with a given value of the voltages V_{h0}, V_b and ΔV_a, and with a given number of stages n, the internal resistance is inversely proportional to the power supplied W_b. A numerical example wil show that a considerable power W_b is needed to arrive at a reasonable value of R_{i_0} (at least if no particular steps are taken, to which we shall refer presently).

Let us say that $n = 3$, $V_{h0} = 25$ kV, $V_b = 350$ V, $\Delta V_a = 280$ V, $R_h = 250$ megohms. To reach a value of R_{i_0} amounting for instance to 2% of R_h (thus 5 megohms), according to (8) W_h must be well over 60 W. This means not only that the efficiency would be very low (the output being only a few watts) but that the anode current would have to have the high mean value of 175 mA.

This difficulty has been solved by using an automatic control voltage on the control grid of the pentode (fig. 1). This control voltage, which is dependent upon the amplitude of the voltage peaks on the circuit L-C_p, is obtained by rectifying the alternating voltage induced in a winding coupled to the coil L. This automatic control permits only a small drop in the direct voltage when the load current increases from zero to a certain limit, without any great amount of power having to be supplied; consequently eq. (8) then no longer holds. At loads exceeding the limit referred to, however, the voltage drops quickly. This is a valuable property of the system, since a short-circuit of the D.C. terminals is rendered relatively harmless thereby.

In order to increase the sensitivity of the control to the utmost extent two measures have been adopted:

1) The winding is connected in such a way that it is the voltage proportional to the peak V_2 that is rectified; as already observed (fig. 7), the variation with the load is greater in V_2 than in V_1.

2) A constant direct voltage bias is connected in series with the alternating voltage to be rectified; consequently, with fluctuating load the percentage of the variation in the resulting control voltage will be greater than that in the induced alternating voltage. Details of this device will be found below where a practical example is considered.

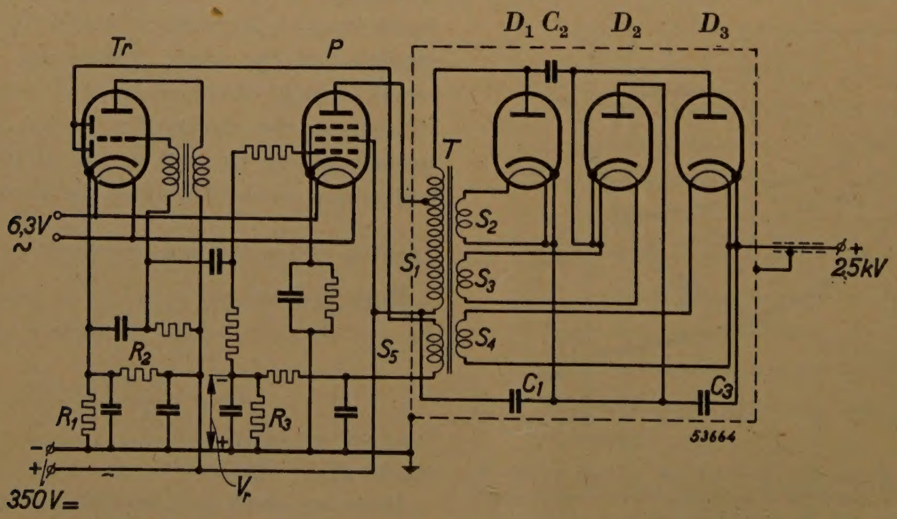

Fig. 9. Complete circuit diagram of pulse generator and rectifier. Tr = triode EBC 33 for producing the saw-tooth voltage, P = pentode EL 38 with the coil S_1 of the transformer T in the anode circuit. S_2, S_3, S_4 = cathode current winding of the diodes D_1, D_2, D_3 (type EY 51). S_5 = winding for control voltage V_r. The circuit is fed with 350 V direct voltage.

Practical execution

We shall now show the ideas set forth above have been realized in an apparatus supplying the cathode-ray tube of a projection-television receiver.

Fig. 9 is a circuit diagram of this supply unit, designed for a direct voltage of 25 kV and a maximum direct current of 150 μA (thus more than sufficient for the cathode-ray tube MW 6-2[7]), described in article II), whilst at a small load the internal resistance does not exceed 5 megohms.

On the left-hand side of the diagram a blocking oscillator is shown with the triode EBC 33. This oscillator supplies a saw-tooth voltage (frequency about 1000 c/s) to the control grid of a pentode EL 38, in the anode circuit of which a part of the coil S_1 is connected to serve as autotransformer (T).

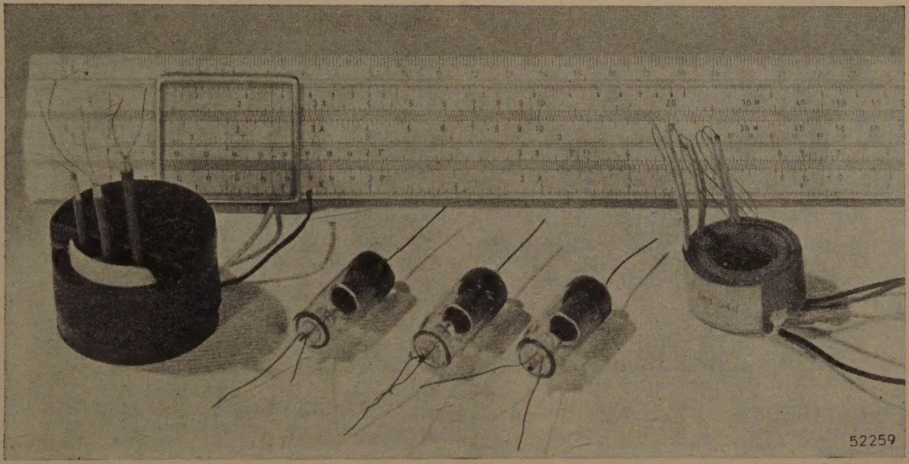

Fig. 10. In the middle the three diodes EY 51 (inverse peak voltage 20 kV, saturation current approx. 200 mA, length of the bulb 40 mm, diameter 14 mm). On the left the complete transformer T of fig. 9. On the rigth the coil of the transformer.

By employing voltage-trebling ($n = 3$) the peak voltage occurring at the coil S_1 is limited to about 8.5 kV. The rectifying valves (type EY 51, *fig. 10*) have been designed for a peak inverse voltage of 20 kV. The saturation current is about 200 mA. The power for heating the filaments (0.5 W) is drawn from a coil (S_2, S_3, S_4, fig. 9) consisting of a few windings coupled to S_1.

The alternating voltage required to furnish the control voltage V_r is induced in another winding (S_5) of the transformer T (fig. 9). This alternating voltage is rectified by means of the diodes contained in the valve EBC 33. For the bias — the object of which is to make the control voltage more dependent upon the load than the voltage across S_5 — use is made of the voltage across the cathode resistor R_1. This voltage is produced partly by the load current of the valve EBC 33 and partly also by an auxiliary current led through R_1 via a resistor R_2. The control voltage V_r ultimately appears across a resistor R_3 in the control grid circuit of the valve EL 38.

The five coils mentioned are wound on a ferromagnetic core of "Ferroxcube" [8]). Owing to the high relative permeability (about 800) and the low losses of this material, it is possible to keep the core small, and still maintain a high circuit quality. Figs. 10 and *11* show a form of the core ensuring a good magnetic screening.

Of course with the high voltages occurring here a transformer of such small dimensions cannot be operated in air. Consequently it is housed, together with the three diodes and the three cascade capacitors C_1, C_2, C_3, in a metal box filled with oil under vacuum and hermetically sealed.

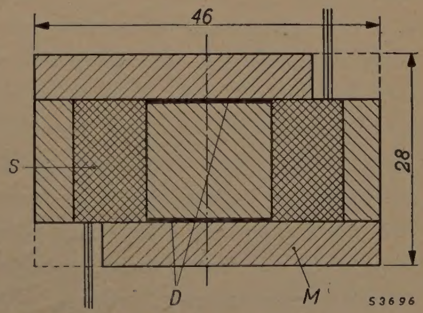

Fig. 11. Cross-section of the transformer T (confer figs 9 and 10) at approximately true size. S = coil, M = magnetic circuit consisting of four pieces of "Ferroxcube" and two air gaps D. Dimensions in millimeters.

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[7]) Thanks to the presence of the smoothing capacitor to be mentioned presently, during a short time current impulses can be supplied which are much greater than 150 μA, without causing the direct voltage to drop too much.

[8]) J. L. Snoek, Non-metallic magnetic material for high frequencies, Philips Techn. Rev. 8, 353-360, 1946.

The positive terminal is connected to the cathode-ray tube by means of a flexible cable insulated with polyvinyl chloride, a material which is not only a very good insulator but is also resistant to oil. The outside of the cable has a conducting layer that is earthed. The end of the cable is provided with a plug which fits onto the anode connection of the cathode-ray tube and which contains a series resistor of 1 megohm. This serves a double purpose. In the first place, together with the capacitance between the inner and the outer envelope of the cathode-ray tube (about 300 pF), it forms a smoothing filter for the ripple voltage. In the second place it limits the current impulse which in the event of a short-circuit would discharge the cascade capacitors; without the resistor this would lead to undesired voltage surges.

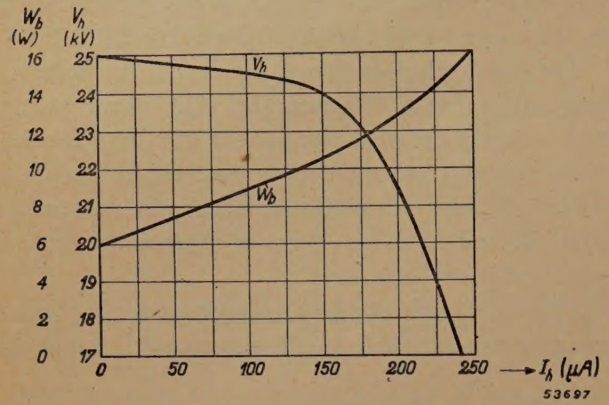

Fig. 12. Direct voltage output V_h and direct current power consumption W_b as function of the direct current output I_h.

In *fig. 12* the direct voltage output V_h and the dissipated power W_b are plotted as functions of the current output I_h. It is seen that V_h at first drops only a little when the current increases, but at $I_b >$ approx. 175 μA it drops sharply, and that W_h (9 W at 100 μA, 11 W at 500 μA) compares very favourably with the value which, as calculated above, would be needed without automatic control (60 W).

Fig. 13 gives an idea of the appearance of the apparatus that has been designed in this manner, the dimensions of which are approximately 10 cm × 15 cm × 18 cm (4″ × 6″ × 7″). As regards the place it occupies among the other component parts of the television receiver, reference is made to fig. 7 of article I.

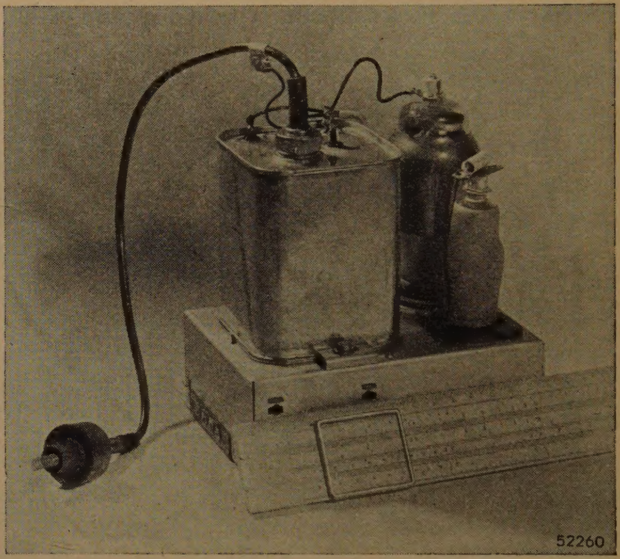

Fig. 13. The complete apparatus for converting 350 V direct voltage into 25 kV direct voltage. On the right the valves EBC 33 and EL 38 and to the left of these the oil-filled can containing the rectifying part. On the extreme left the cable for connecting the cathode-ray tube. The height of the apparatus is 18 cm (7″) and the base occupies 10 cm × 15 cm (4″ × 6″).

STABILIZATION OF THE ACCELERATING VOLTAGE IN AN ELECTRON MICROSCOPE

by A. C. van DORSTEN.

621.385.833:621.316.722.1

The accelerating voltage in an electron microscope must be kept constant to a high degree. The high-voltage generator constructed for the experimental electron microscope of the Institute for Electron-Microscopy at Delft (Laboratorium voor Technische Physica der Technische Hogeschool) had to answer special requirements because the tension had to be continuously adjustable within an extensive range (50-150 kV) and at any level within these limits it was also necessary to keep the voltage constant within 0.2‰ for at least 30 seconds. This article describes a method for stabilizing the voltage by employing a circuit with a high degree of feed-back. At the same time a solution is given for the problem related to the occurrence of relatively large capacitive currents, a problem typical of a system which supplies a small current at a relatively high voltage. With the method chosen the required voltage stability is mainly brought about by means of two regulating valves.

In order to derive full benefit from the high resolving power attainable with electron microscopes having magnetic lenses, the accelerating voltage of the electrons must be highly stable. After the appearance of the first magnetic electron microscopes about 1934, it was a number of years before one realized what requirements had to be met in this respect by the electrical apparatus. In a certain sence the progress made has gone hand in hand with the improvement of the voltage stability of the apparatus.

Permissible variations in voltage

In a previous article published in this journal [1]) it has already been shown how variations in the accelerating voltage affect the quality of the picture. When a magnetic lens is excited with a perfectly constant current its focal distance is proportional to the potential difference through which the electrons have passed. Consequently electrons having different velocities caused by different accelerating voltages do not converge into the same focal point. Optically this means that the lenses are subject to chromatic aberration. Whereas in optics this aberration can be neutralized by a combination of two kinds of glass, in the case of electron lenses such a neutralization is as a rule impossible.

Only such variations of the accelerating voltage are allowed therefore which lead to a blurring not worse than the minimum useful resolving power and certainly no greater than the image fault resulting from diffraction effects and spherical aberration.

The axial chromatic aberration, i.e. the variation of the position of the image measured along the axis, is independent of the lens aperture used, but the corresponding size of the circles of confusion is directly proportional therefore. Lest for a given minimum definition unnecessarily high demands should be made in respect of voltage stability, the aperture — which is given by the size of the condenser diaphragm and the degree of excitation of the condenser lens — must not be chosen too large. As a rule it will have to be smaller than the image of the source of the electron emission, the cathode, projected upon the object. This is, it is true, opposed to the desire to obtain an image as bright as possible, for which purpose the electron density in the beam where it strikes the object has to be raised as high as the object can withstand. However, the loss suffered in this respect owing to the defocusing of the condenser can easily be compensated by increasing the electron emission of the cathode, by heating it to a higher temperature. The resultant shortening of the lifetime of the cathode is not a serious loss, since the cathode is easily replaced.

In this article it will be explained how the accelerating voltage has been stabilized in the high-voltage generator for the electron microscope of the Institute for Electron-Microscope at Delft (Laboratorium voor Technische Physica der Technische Hogeschool). The arrangement and the properties of this instrument have already been described in the article referred to in footnote [1]). A quantitative consideration on the lines indicated above which we shall not go into further here, shows that for this electron microscope the voltage variations are not allowed to exceed about 0.2‰. Since this particular microscope is of an experimental character the high-voltage generator has been so constructed that the voltage can be continuously varied between 50 and 150 kV. Care had to be taken to ensure that within this extensive range the required degree of stability for any voltage setting would be maintained for a period of at least 30 seconds, the time which under normal conditions may be considered sufficient both for focusing the image and for recording the micrograph on a photographic film.

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[1]) J. B. Le Poole, A new electron microscope with continuously variable magnification, Philips Techn. Rev. 9, 33-45, 1947, (No. 2).

Principle of the circuit

With the aforementioned requirements in mind we chose a circuit which includes two amplifying valves regulated in such a way as to keep the current intensity highly independent of the voltage supplied to the system. The constant current thereby obtained is passed through a high-stability resistor and the very constant potential difference thus obtained across the resistor forms the voltage source with the properties desired.

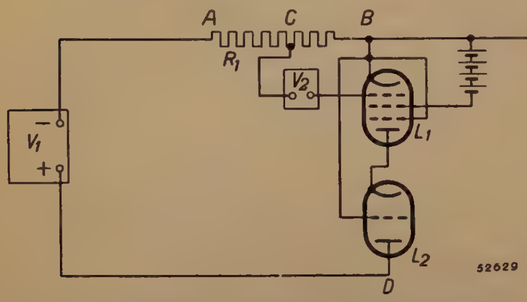

Fig. 1. Circuit diagram applied for the stabilization of the constant potential for an electron microscope. V_1 = the voltage supplied by the rectifier, V_2 = a highly constant reference voltage; R_1 is a high-stability resistor, L_1 a pentode and L_2 a triode. The electron microscope is shunted across the resistor between A and B.

The lay-out of this circuit is diagrammatically represented in *fig. 1*, where V_1 represents the voltage supplied by a rectifier, L_1 and L_2 are the two amplifying valves and R_1 is the high-stability resistor tapped at C in such a way that the part between C and D can be for instance one-thousandth part of the resistance between A and B. The point B and thus the positive side of the voltage on the electron microscope is earthed. The control grid of L_1 is connected to the point C via a highly constant reference voltage V_2. Owing to the voltage difference between B and C, the grid of L_1 becomes rather highly negative with respect to the cathode, but the compensating voltage V_2 holds it at a potential only slightly negative with respect to the cathode, so that the valve L_1 works at its normal bias.

Now, small changes in the grid voltage of L_1 cause large variations on the anode voltage. The voltage amplification obtained by this arrangement is practically equal to the amplification factor of the pentode, which can easily have a value of about 3000. By applying the voltage between cathode and anode of the pentode as grid voltage to a second valve L_2 — if necessary also compensated by a second reference voltage source — the voltage variation is once more amplified. If, for instance, a triode with a voltage amplification of 100 is chosen for L_2, the total voltage amplification becomes 300 000 ×, that is to say that a small variation in the grid voltage of L_1 is 300 000 times greater between cathode and anode of L_2.

It is easy to see that there is a persistent trend to a constant current through the resistor R_1. If with a rising voltage V_1 the current through R_1 increases, the point C would acquire a more negative potential with respect to B, as a result of which the voltage across L_1 would increase and, consequently, that across L_2 likewise. The higher voltage across the valves L_1 and L_2 reduces the voltage V_1, so that the assumed variation in the voltage between A and B is neutralized. The voltage variations of V_1 thus show themselves only as practically equal variations of the voltage of point D (in fig. 1) with respect to B. As long as the grid potentials of L_1 and L_2 remain within the normal range, in this manner a highly stable circuit is obtained.

The general control features of the circuit described here need not be discussed further since they are entirely analogous to those of other control circuits previously dealt with in this journal [2]). We shall confine our considerations to the details relating to the fact that here the voltages are much higher and the currents much lower than those found with stabilizing circuits for measuring and radio purposes.

The difficulties arising from the high voltage are not connected to problems of insulation and the like but rather in the occurence of **displacement currents**, the consequences of which may have a very disturbing effect upon the controlling properties.

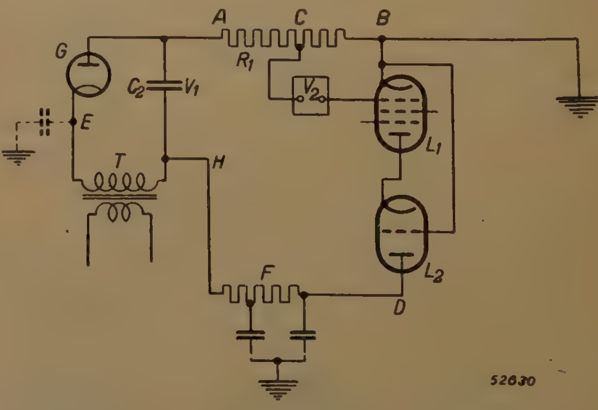

Fig. 2. Diagram of the system of fig. 1 further extended to include the high-tension transformer T and the rectifying valve G, a smoothing condenser C_2 as well as a filter F to eliminate the alternating voltage arising from the capacitive current flowing from the high-tension terminal of the transformer to earth.

Fig. 2 is another schematic diagram of the circuit including the high-tension transformer T

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[2]) H. J. Lindenhovius and H. Rinia, A direct current supply apparatus with stabilized voltage, Philips Techn. Rev. 6, 54-61, 1941.

and the rectifying valve *G* and showing (in dotted lines) the capacitance at the high-tension terminal *E* of the transformer *T* with respect to earth. Due to the alternating voltage at this point a current flows via this capacitance also through the valves L_1 and L_2. This capacitive current may reach a considerable amplitude which may even be many times greater than the useful direct current supplied by the apparatus.

This capacitive current from the supply transformer to earth occurs in principle also in highly stabilized direct voltage sources as developed for radio and measuring purposes (see the article quoted in footnote [2])), but owing to the low voltage and the relatively large direct current the ratio of the undesired alternating current i_c to the direct current i_g to be supplied is of an entirely different order of magnitude. In the high-tension apparatus for an electron microscope the ratio i_c/i_g may easily be a factor 10^5 greater than that of an apparatus for low voltages and large currents.

As a consequence of this capacitive current to earth, a considerable alternating voltage would come across the regulating valves L_1 and L_2 in fig. 2 and interfere with the whole control. In order to remedy this, a filter *F* can be introduced as shown in the diagram. It is in fact possible to eleminate this undesired voltage by this means, but there is a resultant undesired time lag.

Another and more effective method of eliminating this undesired capacitive current is to provide an electrostatic screening which prevents this current flowing to earth and directs it straight to the low-potential terminal *H* of the supply transformer *T*. This screening should envelop the windings of *T* as completely as is possible. An obvious solution is to choose the transformer box for this.

The presence of the filament transformer for the rectifying valve *G*, is likewise a cause of a capacitive leak current to earth. This can be rendered harmless by using an intermediate transformer and connecting the intermediate windings to the screen. In a rectifier for voltages of the size required here, 160 kV, for practical reasons two rectifying valves in a voltage-doubling circuit are to be preferred to one single rectifying valve, because this halves the inverse voltage. *Fig. 3* shows the circuit diagram incorporating these improvements.

Special attention has also been paid to the speed of regulating. A rapid variation, periodically or not, of the high negative potential at the point *A* in fig. 1 must be followed without troublesome inertia by a corresponding though much smaller potential change at the point *C* in the same figure, to which the grid of the control valve L_1 is connected. Since between *A* and *C* there is a resistance of 10^8 ohms, a small capacitance at the point *C* with respect to earth would already cause a delay in the corrective action of the control, which would defeat the object in view.

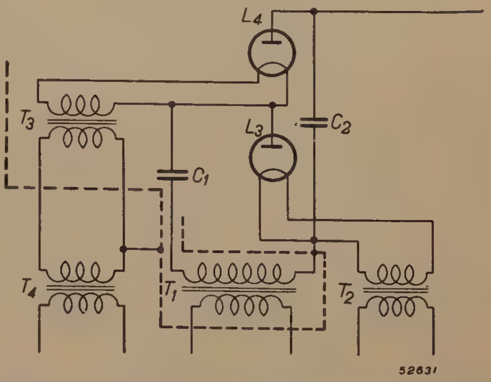

Fig. 3. Part of the circuit showing how voltage doubling is obtained for the high-tension rectifier. T_1 is the high-tension transformer, whilst the dotted line represents the transformer box acting as an electrical screen. The common circuit of the transformers T_3 and T_4 is connected to the screening box of T_1 in order to carry off the capacitive current.

This can be avoided by bridging the resistor between *A* and *C* with a condenser. This would then be in parallel with the electron microscope, which is undesired because in the event of a disturbance this condenser would discharge a high, undamped, current in the space between cathode and anode. By introducing a resistor in series with the capacitor the current can be sufficiently damped to ensure that in the event of such an interference the electron microscope suffers no harm.

Further, it is to be pointed out that in the practical application of this system it was found desirable to connect the apparatus supplying the compensating voltage V_2 between *B* and the cathode of L_1 instead of between *C* and the control grid of L_1. This was to avoid increasing the input grid capacity of the pentode by the capacitance unavoidable in this apparatus.

It has already been mentioned that the required degree of voltage stability has to be maintained for at least 30 seconds, the period considered sufficient for focusing and taking a micrograph. To meet this requirement not only must the mains voltage variations be compensated but care has also to be taken that no inadmissible changes take place in the circuit elements during that period. What is most to be avoided is a variation in the resistor R_1 and this requirement has been met by applying oil-cooling and selecting a resistance wire with a small temperature coefficient.

Before proceeding to give a further description of the high-voltage generator at Delft we must draw attention to the fact that the demands made for that experimental electron microscope differed considerably from what is usually required of such an apparatus. In the first place it was quite unusual to require continuous adjustability in a range of 100 kV, whilst on the other hand the nature and purpose of the instrument left the designer more freedom as regards the dimensions of the installation, since it did not have to be set up in a particular small space. This made it possible, for instance, to use metal wire for the high-ohmic resistor R_1, shunted across the microscope proper, so that this resistor could be given exceptional properties but was much larger than carbon resistors; the wire is wound on a cylinder no less than 1.80 metres long.

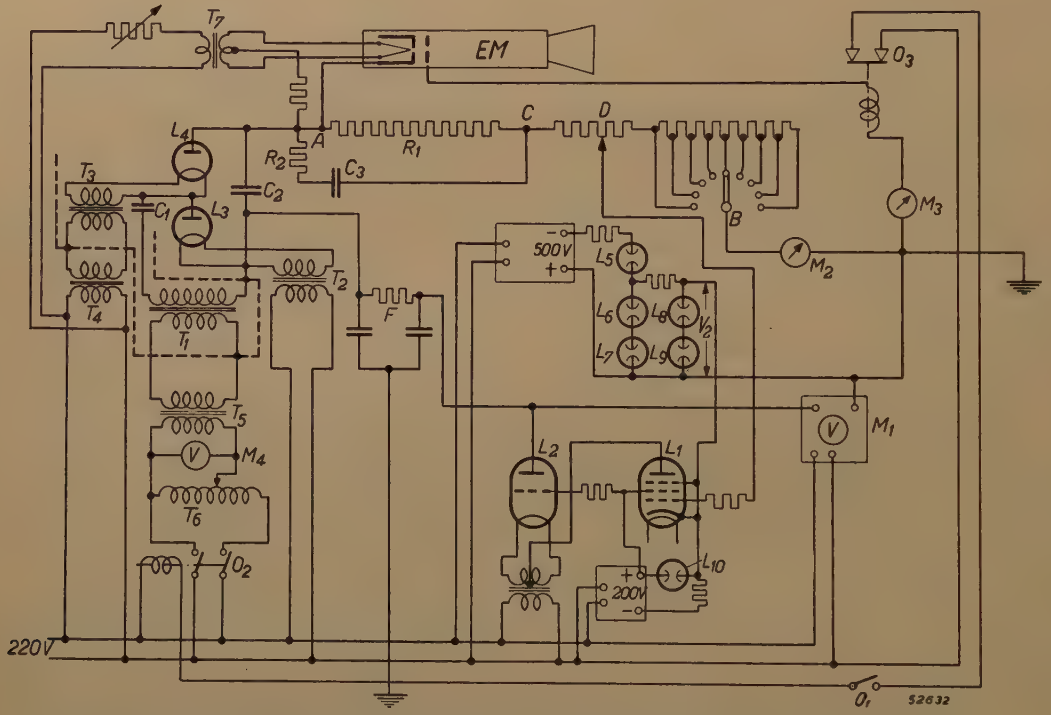

Fig. 4. Circuit diagram of the high-tension installation of the experimental electron microscope for 150 kV installed in the Institute for Electron-microscopy at Delft. *EM* is the electron microscope, L_1 and L_2 are a pentode and a triode repectively, L_3 and L_4 two rectifying valves, L_5-L_{10} neon stabilizing valves, M_1-M_4 measuring instruments, O_1-O_3 switches, T_1-T_7 transformers, F a filter. The box of the high-tension transformer is again represented by a dotted line. In so far as this circuit relates to the high-tension rectifier, the following is to be noted: The transformer T_1, connected on the primary side to the regulating transformer T_6 via the intermediate transformer T_5, supplies on the secondary side a voltage with a maximum peak value of 80 kV. C_1 is a condencer having a value of 0.05 µF. Since the load current is small (1-2 mA), at maximum voltage this condenser is charged almost up to 80 kV, the peak value of the transformer voltage, via the high-tension valve L_3 (type 28122). The pulsating voltage, amplitude about 2 × 80 kV, across this valve causes the condenser C_2, with a value of 0.025 µF, to be charged via the valve L_4 to a voltage of about 160 kV. The circuit of the regulating apparatus is explained in the text.

Description of the installation

The high-tension installation described in this article was made in the Philips Laboratory at Eindhoven. Its circuit diagram is given in *fig. 4.*

For the sake of clarity the description of the apparatus is divided into three parts: 1) the rectifier for the high tension, 2) the stabilized resistor, 3) the regulating apparatus with compensating device.

The rectifier for the high tension

For the reason already given, voltage-doubling with two valves was used for generating the high constant potential.

It is not necessary to go into the details of the circuit of this rectifier because it has already been fully described in this journal [3]. Numerical data are given in the legend of fig. 4.

The filaments of the valves L_3 and L_4 are fed via transformers. The secondary winding of the transformer supplying L_3 is insulated for 20 kV. The filament of L_4 is fed via a transformer insulated for 180 kV, connected to the mains on the primary side via an intermediate transformer insulated for 20 kV and with its secondary winding connected, like that of the valve L_3, to the box of the high-tension transformer T_1, to carry off the capacitive current which otherwise, as explained above, would flow to earth. A metal screen can also be affixed to the box of this high-tension transformer to render the capacitive current from other parts of the installation harmless.

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[3] Philips Techn. Rev. 1, 6-10, 1936; 2, 161-164, 1937.

High-stability resistor

The high-stability resistor R_1 consists of a coil of resistance wire with a low temperature coefficient helically wound on a cotton core. This in turn is wound on a glass cylinder 12 cm in diameter which is mounted inside a vertical column consisting of sections of high-voltage grade "Philite" screwed one into the other. Rings of the same kind and similar ones of larger size have also been used for the jackets of the high-tension condensers C_1 and C_2, the filament transformers of the rectifying valve L_4 and the transformer T_7 for the electron microscope.

High-tension resistors made in this manner are apt to show sometimes irregular deviations in the resistance, this being due to the fact that in the process of winding breaks are apt to occur in the 15 μ thick wire; when the electric power is switched on, the cotton core becomes carbonized locally where those breaks occur and since these carbonized points are conductive, the interruptions are shunted thereby. The resulting very small increases of the resistance often pass unnoticed in the beginning. In order to eliminate such defects, while the column was being wound tests were made to make sure that the resistance increased strictly linearly with the length of the wound wire. The abnormal spots were detected by graphical means and the breaks bridged over. In this manner a resistor was produced which satisfied the most stringent requirements.

The regulating apparatus with compensating device

An important part of the regulating apparatus is the compensating device, which has to supply the highly stabilized voltage V_2. A small rectifier supplies 500 V direct voltage, from which, by means of a two-fold stabilization with successively three and two neon stabilizing valves L_5 to L_9 (type 150 A1) connected in series, the highly constant reference voltage V_2 is obtained, which together with the potential difference between the points B and D determines the voltage difference between grid and cathode of the pentode L_1 (type EF 6). The grid is connected directly to the point D, the sliding contact of the potentiometer. The point B is the contact arm of a tapped resistor with constant properties. In this manner it is possible to modify the resistance between the points B and D both step by step and continuously; for each setting there is a definite current passing through the total resistance between A and B. The difference between the constant voltage V_2 and the voltage between the points B and D thus brings the regulating valve into the working point. The adjustment is such that the anode voltage of the valve L_1 then amounts to about 200 V.

The voltage between the anode of L_1 and earth is now identical with the voltage between grid and cathode of the valve L_2 (type TA 8/300), but since the latter would then have too high a negative grid bias its grid is not connected directly to earth, as in fig. 1, but via a suitable voltage source. For this purpose the same voltage source can be used as is required to keep the screen grid of L_1 at a constant potential with respect to the cathode. In this case a small rectifier is used together with the

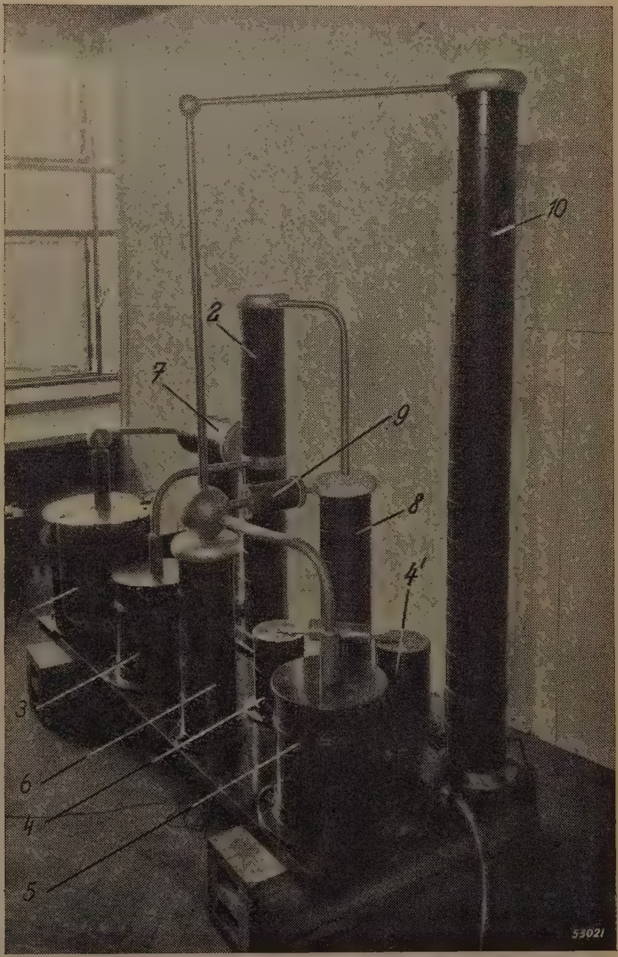

Fig. 5. The high-tension installation of the 140 kV electron microscope installed at Delft. *1* is the high-tension transformer, *2* the column with the two high-tension valves, *3* their filament transformers, *4* and *4'* the parts of the filter, *5* the filament transformer for the electron microscope, *6*, *7* and *8* condensers, *9* a smoothing resistor, *10* the high-stability resistor mounted on a cylinder 1.80 metres in length. (The smoothing condenser *6* and the smoothing resistor *9* are not shown in the diagram of fig. 4; they would have to be shunted across C_2.)

neon stabilizing valve L_{10} (type 150 A1). This rectifier supplies a voltage of 150 V. In this manner a good adjustment of the valve L_2 is obtained, which can take up an anode voltage varying for instance between 1000 and 15000 V according to the grid voltage and thus ultimately dependent of the potential of the control grid of L_1.

The working voltage of the electron microscope is therefore selected by means of the adjustment of the resistor between B and D, the voltage applied by the rectifier being so adjusted, by means of the hand adjustment of the regulating transformer T_6 ,that the regulating valve L_2 comes to lie in the middle of the regulating range and thus takes up a voltage of about 7000 V. In order to check this adjustment, between the anode of L_2 and earth a valve voltmeter M_1 is connected which has an extremely high input resistance and acts practically speaking as an electrostatic voltmeter. This meter indicates the voltage fluctations that are "smoothed out". This renders it possible to check the working of the circuit at any time. Mains voltage fluctuations up to 5%, positive as well as negative, can be controlled in this manner. Larger deviations, which hardly ever occur in the form of fluctations, have to be adjusted with the aid of the regulating transformer T_6.

The circuit of fig. 4 further shows some of the devices already described above, such as the condenser C_3, which transmits the rapid variations to grid of L_1, and the filter F which suppresses what is left of the capacitive current, particularly the higher harmonics of the 50 c/s current.

Further, the diagram shows that some control meters have been introduced: M_4 is a voltmeter for the primary transformer voltage, M_3 a milliammeter for the emission current of the electron microscope, M_2 a milliammeter for the current passing through the potentiometer. O_1 is the switch controlling the excitation of the magnetic switch O_2 and thus the high-tension rectifier. O_3 is a overload relay which interrupts the energizing current of O_2 as soon as the current in the electron microscope reaches an abnormally high value, as may be possible for instance when gas is released or in case of a break in the vacuum system. This automatic cut-out comes into operation as soon as the current exceeds 2 mA. This device precludes discharges that may be harmful to the instrument.

Fig. 5 is a photograph of the high-tension equipment as installed.

Note

The circuit described here represents only one of the many methods that can be applied to obtain a stabilized high tension. The attractiveness of this method lies in its simplicity, the work being done in fact by only two regulating valves.

Finally it is to be noted that with the method described it would also be possible to introduce the regulating valves on the high-tension side of the resistor R_1. The problems connected with the capacitive current would not then arise, but on the other hand there would be difficulties of a constructional nature, particularly so when the voltage is high, as it is the case here.

A RAPID-ACTION STARTER SWITCH FOR FLUORESCENT LAMPS

by Th. HEHENKAMP.

621.327.43.032.433

With the usual types of starter switches for fluorescent lamps, namely the resistance and glow-discharge bimetallic starters, several seconds elapse between the switching on and the ignition of the lamp. Though in many cases of public utility lighting this is no objection, it is of more serious consequence in the illumination of the home, in which field the fluorescent lamp is gaining more and more ground. To overcome this difficulty a new solution has therefore been sought based on the consideration that the cathodes should first be sufficiently heated so as not to suffer any damage when the lamp is ignited. For this heating to take place in a reasonably short time (0.3 to 0.4 sec) a current has to be sent through the filaments which is greater than the stationary short-circuit current of the series choke. This heating current is obtained by utilizing a transient, the circuit being periodically closed and opened by a contact forced to vibrate by means of a coil shunted across it. The time normally elapsing between the switching on and the ignition of the lamp is 0.3 to 0.4 sec, and in unfavourable circumstances 0.5 to 1 sec. The new starter switch is interchangeable with the conventional glow-discharge bimetallic starter.

Tubular fluorescent lamps for general illumination purposes are as a rule of such a construction that the arc voltage amounts to about half the R.M.S. value of the mains voltage for which they are rated. A simple ballast (generally a choke) then sufficies to stabilize the discharge in the lamp[1]).

In order to ignite the lamp it has to be given a voltage impulse higher than the peak value of the mains voltage. Preferably the lamp should not be ignited before the cathodes have practically reached the working temperature, not only because the voltage impulse can then be smaller than when the cathodes are cold, but particularly because ignition with cold cathodes shortens the life of the lamps. For this reason automatic starters have been devised which pass a heating current through the filaments before igniting the lamp. Two types of starters hitherto used will be briefly described before proceeding to deal with a new type.

Starter switches hitherto used

The resistance-bimetallic starter

The so-called resistance-bimetallic starter (S_r, *fig. 1*) consists of a contact having one of its poles fixed to a bimetallic strip and a heating element r in the shape of a coil. Since the contact is originally closed, upon the mains voltage being switched on a current flows through the choke L, the two filaments and the heating element. We call this current the short-circuit current (I_k), because it flows when the lamp is short-circuited. After the filaments have been given time to reach the desired temperature, under the influence of the heat generated in the heating element the bimetal is curved far enough to open a contact and break the short-circuit current. When this opening of the contact takes place at a not too small momentary value of the current, owing to the self-inductance L it is accompanied by a voltage impulse that ignites the lamp. There then flows through the heating element the normal working current, which though less than the short-circuit current is still sufficient to keep the contact open. The cathodes are then maintained at the desired temperature by the discharge itself.

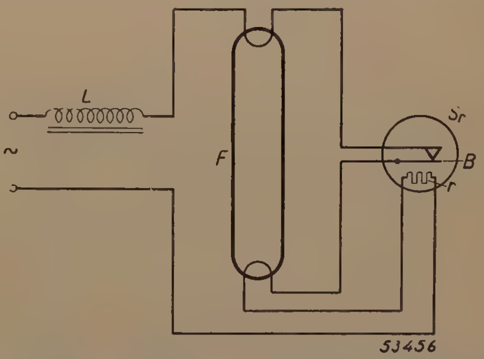

Fig. 1. Circuit diagram of the resistance-bimetallic starter (S_r). F = fluorescent lamp. L = ballast choke. B = bimetal. r = heating coil.

If, however, the opening of the contact takes place at about the zero point of the short-circuit current, then there is no voltage impulse sufficient to ignite the lamp. In such a case the circuit through the heating element remains broken until the bimetal is sufficiently cooled down for the contacts to meet again. This cycle is repeated until ignition of the lamp occurs.

The great objection against the resistance-bimetallic starter is that the initial state (heating element cold, contact closed) differs from the working state (heating element hot, contact opened). The fact is that when a lamp is switched on again a few seconds after it has been switched off, the contact is still open and one has to wait for the bimetal to cool down sufficiently to close the contact. The heating element, however, is then still at a considerable temperature and the contact will open again in a much shorter time than is normally the case. The cathodes of the lamp, which had on the other hand cooled down, are not sufficiently heated again in that short space of time and the voltage peak arising from the breaking of the circuit is not high enough, so that in such a case the lamp does not ignite until the starter action has been repeated several times. The re-ignition times with the resistance-bimetallic starter therefore amount to 10 to 15 seconds.

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[1] A. A. Kruithof, Tubular luminescence lamps for general illumination, Philips Techn. Rev. 6, 65-73, 1941.

The glow-discharge bimetallic starter

The glow-discharge bimetallic starter (S_g, *fig. 2*) likewise consists of a contact having one pole fixed to a bimetallic strip. The heating of the latter however is not brought about by means of a heating coil but by a glow-discharge between the electrodes. The bulb containing these electrodes is filled with a gas of such a nature and pressure as to cause the ignition voltage of the glow-discharge to be lower than the peak of the lowest mains voltage (nominal 220-230 V [2])) but higher than the arc voltage of the fluorescent lamp.

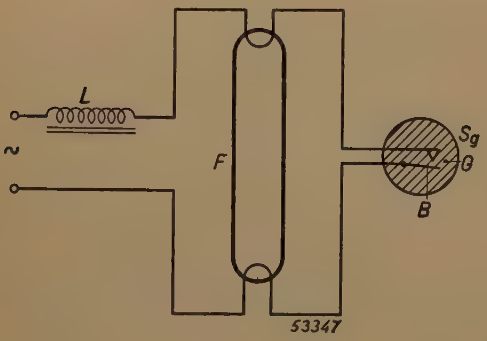

Fig. 2. Circuit diagram of the glow-discharge bimetallic starter (S_g). G = gas filling in which a glow discharge may take place and heat the bimetal. The other letters have the same meaning as in fig. 1.

Another fundamental difference compared with the resistance-bimetallic starter lies in the fact that in the initial state the contact of the glow-discharge bimetallic starter is open.

The latter type of starter works in the following way. As soon as the mains voltage is switched on a glow-discharge takes place in the starter and heats the bimetal, so that after a time the contact is closed. Not until then does the short-circuit current begin to flow and heat the lamp cathodes (the glow current already flowing did not play any appreciable part in this). Simultaneously with the closing of the contact the glow-discharge is extinguished. The bimetal thus cools down, the contact opens after a certain time and the short-circuit current is broken. The voltage impulse thereby arising may be sufficient to ignite the lamp, the cathodes having meanwhile been heated up. The arc voltage of the lamp then comes to lie across the starter, and no glow-discharge can take place; thus the contact remains open. As a rule, however, the first voltage impulse will not be sufficient to ignite the lamp; the cycle is then repeated, possibly several times.

On an average this cycle is repeated many more times with the glow-discharge bimetallic starter than is the case with the resistance bimetallic starter, for in the former case the glow-discharge is first started upon the contact being opened, the voltage peak remaining lower than would be the case without a glow discharge; consequently there is less chance for the lamp to ignite.

Apart from the drawback of this more frequent repetition of the cycle, the glow-discharge bimetallic starter has the objection that the short-circuit current does not begin to flow until the bimetal has been heated. In fact it takes as much as from 2 to 5 seconds before the lamp starts. With the resistance-bimetallic starter this delay is no more than 1 to 2 seconds.

Against this, however, there is the important advantage that with a glow-discharge bimetallic starter the initial state is the same as the working state, viz. no glow-discharge, contact open. Upon the lamp being switched off and then immediately switched on again there is therefore not the objection that arises in the case of the resistance-bimetallic starter.

Another advantage of the glow-discharge bimetallic starter, which though incidental is of practical importance, is the fact that it has only two connecting points (fig. 2), thus greatly simplifying the wiring. The resistance-bimetallic starter on the other hand has four connecting points (fig. 1).

In the course of the last few years various improvements have been made to both these types of starters with a view to minimizing the drawbacks referred to. In most applications the glow-discharge bimetallic starter has gained more favour and is now commonly employed both in Europe and in America.

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[2]) At other nominal values of the mains voltage, say 110 V, 125 V, etc., an autotransformer is used with a secondary voltage of 220 V. This transformer may have such a leakage as to make a separate choke unnecessary. What is said in this article about starters applies also to the case where such a transformer is used.

The properties desired in an improved starter switch

The delay between the switching-on and the ignition of fluorescent lamps is no great objection when these are used in factories, offices, shops and suchlike, but they are beginning to be used on a steadily increasing scale for the illumination of the home 3), where it more frequently happens that a dark room needs to be illuminated immediately upon switching on. In such cases a delay of a few seconds is most annoying. There is therefore undoubtedly a need for a starting device which, if not eliminating this delay entirely, will at least reduce it considerably.

The solution is not to be sought in the raising of the voltage impulse to such a level as to ignite the lamp immediately upon switching on, because this would be detrimental to the life of the lamp, since its durability depends in part upon the number of times it is switched on. In houses the number of times a lamp is switched on is greater than elsewhere, and if the lamp were to be ignited every time while the cathodes are still cold its length of service would be considerably shortened.

We must therefore maintain the requirement that upon the lamp being ignited its cathodes must already have been brought up to a sufficiently high temperature, the latter taking place so quickly as to avoid any inconvenience being experienced from the delay.

Furthermore, a very short re-ignition time is desired when a lamp is switched on again immediately after having been switched off.

Finally, the new starter must be interchangeable with the hitherto conventional glow-discharge bimetallic starter, likewise having only two terminals and the same small dimensions.

Ignition voltage and cathode temperature

The requirement made above, that prior to the ignition of the lamp its cathodes must have reached a sufficiently high temperature in the shortest possible time, leads to the following problems:

1) How high must the minimum temperature of the cathodes be upon ignition in order to avoid excessive sputtering?
2) With what heating current do they reach this temperature in a reasonably short time (e.g. $^1/_3$ sec.)?
3) How can this heating current be obtained?

As to the first question, the following is to be remarked. When the R.M.S. value V_0 of the sinusoidal alternating voltage that just causes the lamp to ignite is measured as a function of the cathode temperature ϑ it is found to follow a curve as indicated in *fig. 3*; raising ϑ above about 400 °C gives practically no further reduction of the ignition voltage.

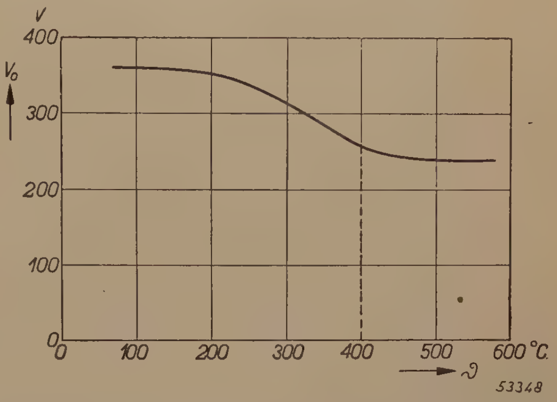

Fig. 3. Ignition voltage V_0 (R.M.S. value of a sinusoidal alternating voltage) of the TL 40 W fluorescent lamp, as function of the cathode temperature ϑ. This graph represents the average of the measured results taken with several lamps.

Now it is known from experience that when the ignition voltage is low there is also little sputtering due to the ignition. It is therefore to be taken as a fact — confirmed in practice — that ϑ need not be raised higher than 400 °C to give the lamp a long life.

The second question has been answered by measuring ϑ as a function of the time t at various constant values of the heating current. This measurement amounts to the recording of an oscillogram of the voltage across the filament while the constant heating current is passing through it. This voltage and current give the resistance of the filament, which resistance increases as the filament gets hot. (This increase of resistance has practically no effect upon the value of the heating current, since the resistance of the hot filament is still small in comparison with the impedance of the series choke.) From the curve representing this resistance one can deduce the temperature with the aid of the temperature coefficient. The wiring diagram used is represented in *fig. 4*, some details of which are explained in the legend.

An oscillogram of the heating voltage is given in *fig. 5*. The curves $\vartheta = f(t)$ derived from such oscillograms for a number of values of the heating current are reproduced in *fig. 6*.

The short-circuit current I_k of the ballast belonging to the TL 40 W lamp is 0.7 A at a mains voltage of 220 V. Extrapolation of the bottom curve in fig. 6 shows that with this current applied as heating current it takes more than 1 sec to reach the temperature of 400 °C. To cut this time down

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3) L. C. Kalff and J. Voogd, Living-room lighting with tubular fluorescent lamps, Philips Techn. Rev. **8**, 267-271, 1946.

to 0.3 sec a heating current of 1 A is required, i.e. a current generating per time unit twice as much heat as the normal short-circuit current I_k.

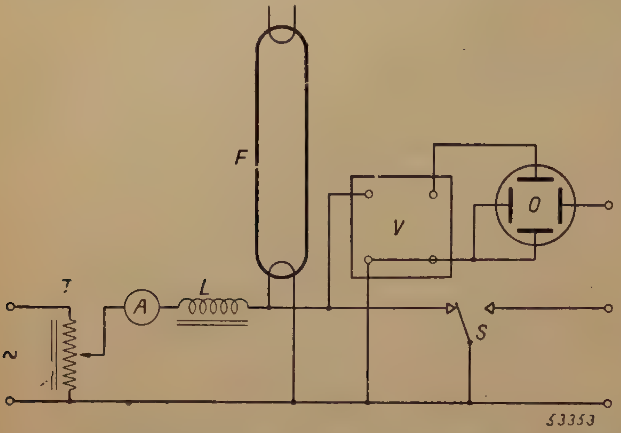

Fig. 4. Circuit diagram for recording the oscillogram of the heating voltage during the heating of the cathode, at constant heating current. F = fluorescent lamp, where the current passing through one of the filaments is preadjusted to the desired value (regulating transformer T, ammeter A). The secondary voltage of T being much higher than the heating voltage, and the excess being taken up in a choke (L), a preadjusted heating current undergoes practically no change while the cathode is heating up. When, with cold filament, the switch S is turned to the right, the filament is no longer short-circuited and the heating voltage, via the amplifier V, causes a vertical deflection on the oscillograph screen O. At the same time the right-hand contact of S activates a device which supplies a voltage rising proportionately with the time. This voltage causes the light spot to traverse the screen horizontally in about 0.5 sec.

The value of I_k could be raised to 1 A (while retaining the normal working current) by constructing the choke in such a way that the induction in the core is higher up in the saturation zone, but then this would involve a noticeable distortion of the working current and relatively large current variations following fluctuations in the mains voltage.

A better method has been found by utilizing the fact that the current arising when an alternating current circuit is switched on is apt to assume extra large values temporarily.

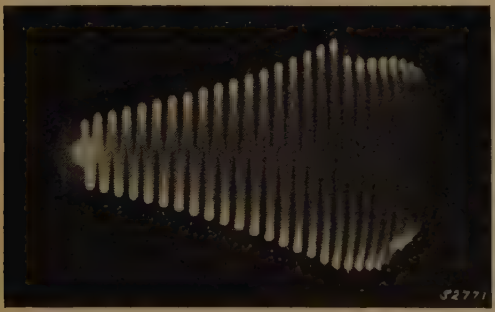

Fig. 5. Oscillogram showing the heater voltage of a TL 40 W lamp taken up in the circuit of fig. 4. The heating current is 1 A, 50 c/s. At first the heater voltage rises owing to the positive temperature coefficient. After 17 cycles ($^1/_3$ sec.) the heater voltage had risen to such a high level (12 V) as to cause a gas discharge to take place parallel to the filament, this accounting for the resulting drop in the heater voltage.

Transient occurring when switching on a circuit with self-inductance and resistance

When a circuit consisting of a self-inductance L with a resistance R in series is connected to an alternating voltage source $v = V_{\max} \sin \omega t$, we have for the current i the differential equation

$$L \frac{\mathrm{d}i}{\mathrm{d}t} + Ri = V_{\max} \sin \omega t.$$

The solution of this equation for constant values of L and R is:

$$i = \frac{V_{\max}}{Z} \sin(\omega t - \varphi) + C e^{-\frac{R}{L}t} \quad . \; . \; . \; . \quad (1)$$

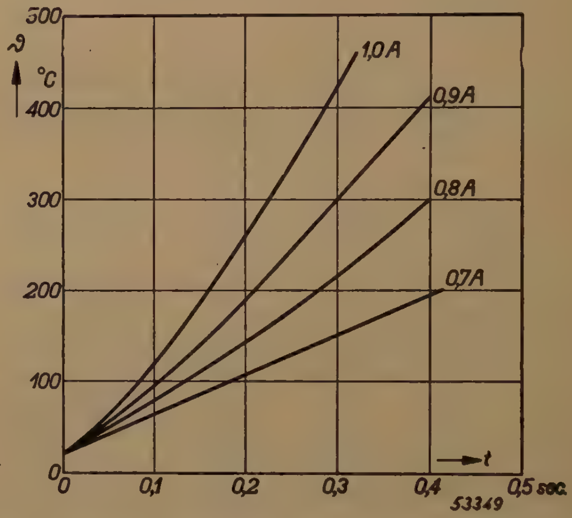

Fig. 6. Cathode temperature ϑ as function of the time t at constant values of the heating current.

The first term in the second member represents the stationary solution, where Z is the impedance, $\sqrt{\omega^2 L^2 + R^2}$, and φ is the phase difference between this stationary current and the mains voltage: arc tan $\omega L/R$.

The second term on the right-hand side of (1) represents the transient. The constant C is governed by the moment t_0 at which the circuit is switched on (the solution has to satisfy the condition $i = 0$ for $t = t_0$). Hence we have the following form of the solution applicable for all values of $t \geqq t_0$:

$$i = \frac{V_{\max}}{Z} \left[\sin(\omega t - \varphi) - e^{-\omega(t-t_0)\,\mathrm{cotan}\,\varphi} \cdot \sin(\omega t_0 - \varphi)\right] =$$

$$= \frac{V_{\max}}{Z} \cdot y. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

In *fig.* 7 the quantity $y = iZ/V_{\max}$, which is a measure for the current i, is plotted in a heavy line as a function of ωt for one value of φ ($\varphi = 78°$, $\cot \varphi = 0.21$). The figs 7*a*-*d* relate to four values of the switching-on moment t_0 given in the legend. The dotted sine line represents the mains

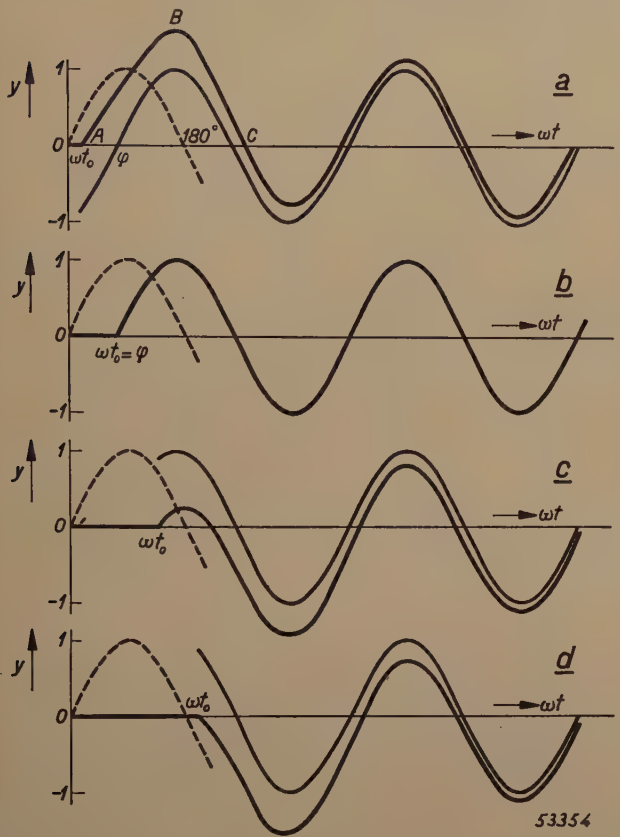

Fig. 7. Curves of the current arising when a circuit consisting of a constant resistance R and a constant self-inductance L connected in series is connected to an alternating voltage source $\vartheta = V_{\max} \sin \omega t$. Plotted in heavy lines is $y = iZ/V_{\max} = f(\omega t)$ according to equation (2) for $\varphi = 78°$ and *a*) $\omega t_0 = 18°$, *b*) $\omega t_0 = 78° = \varphi$, *c*) $\omega t_0 = 138°$, *d*) $\omega t_0 = 198°$. The dotted line represents the mains voltage: $v/V_{\max} = \sin \omega t$; the light sine line represents the stationary current: $\sin(\omega t - \varphi)$.

voltage curve, the lightly drawn sine line representing the stationary current. From formula (2) and fig. 7*b* we see that the current follows the stationary curve immediately after switching on when $\omega t_0 = \varphi$, thus when the circuit is closed at the moment at which the stationary current, if present, would pass through zero. With other values of ωt_0 however a transient is superposed upon the stationary current (figs 7*a*, *c*, *d*). As a consequence the current peaks (in absolute value) are alternately higher and lower than those in the stationary state.

The new starter

Principle

In the new starter described here use is made of the high current peaks referred to above in order to get the desired rapid heating of the cathodes. The circuit *L*-*R* upon which we worked in the preceding paragraph is now composed of the self-inductance L_1 of the choke and the sum R_1 of the loss resistance of that choke and the resistance of the two filaments (*fig. 8*).

The desired heating cannot be obtained with only one current impulse (for instance *ABC* in fig. 7*a*), it being necessary to repeat the impulse during say from 15 to 20 successive periods, thus during an interval of time of about $^1/_3$ sec. This implies that the current must be repeatedly interrupted. The switching contact, which is shunted across the lamp just as in the case of the glow-discharge bimetallic starter (fig. 2), is therefore kept in vibration by a magnetic coil while the cathodes are heating up. This coil is connected across the contact (fig. 8), so that upon the armature being attracted the coil is short-circuited, the contact then opening, and so on. Once the lamp has been ignited the contact remains open, because then the arc voltage of the lamp across the magnetic coil is not sufficient to close the contact.

From the foregoing it will be evident that for proper functioning one is not entirely free in the choice of the moments at which the contact closes and breaks the circuit: as we have seen from fig. 7, it depends upon the switching-on moment what proportions the transient assumes, and the switching-off moment must be so chosen that the filaments are without current during the shortest possible time.

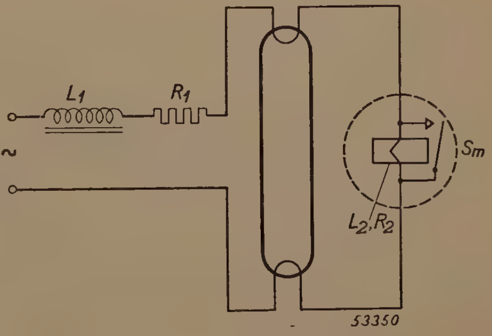

Fig. 8. Circuit diagram of the electromagnetic starter switch (S_m). L_1, R_1 and L_2, R_2 represent the self-inductance and resistance of the ballast choke (including the filaments) and of the magnetic coil respectively.

Another important point is that these moments must be so chosen that the heating effect is only slightly dependent upon small inevitable variations in the switching moments. A further quantitative analysis is therefore required, even though various effects arise which cannot very well be taken into account. Then there comes the question how to bring about the switching operations at the desired moments.

The chosen frequency f_c at which the contact vibrates is equal to the mains frequency f. This is not absolutely necessary, some other simple relation between f_c and f being possible, for instance $f_c = 2f$, or $2f/3$; the calculation in such cases is analogous to that given below for $f_c = f$. It appears that when $f_c > f$ the result is so strongly dependent upon the switching moments that for practical purposes this case is unsuitable. When $f_c < f$ another difficulty arises, to which we shall refer later. $f_c = f$ proves to be a satisfactory compromise.

Choice of the switching-on moments

First of all it is to be noted that with a given ballast the quantities R_1, L_1 and ω are fixed, thus also the impedance Z_1 and the phase angle φ_1. Thus for the 40 W lamp in question cotan $\varphi_1 =$ approx. 0.21, $\varphi_1 =$ approx. 78°; it is upon this value, for which the curves have been drawn in fig. 7, that the following calculations are based.

The amount of heat w generated by the passage of the current through each of the filaments (resistance R_f [4])) amounts to:

$$w = \frac{R_f}{\omega}\int_{\omega t_0}^{\omega t_0+\delta} i_1^2\,\mathrm{d}(\omega t) = \frac{R_f}{\omega}\cdot\frac{V_{\max}^2}{Z_1^2}\int_{\omega t_0}^{\omega t_0+\delta} y_1^2\,\mathrm{d}(\omega t). \quad (3)$$

where δ is the angle corresponding to the time elapsing between switching-on and a switching-off and y_1 is the expression between brackets in formula (2) for a given angle φ_1.

We shall now compare the quantity w given by (3) with the amount of heat w_s which could be generated in the same resistor R_f in the full cycle (2π) by the stationary current $i_s = (V_{\max}/Z_1)\sin(\omega t - \varphi)$, the R.M.S. value of which we have previously called I_k:

$$w_s = \frac{R_f}{\omega}\cdot\frac{V_{\max}^2}{Z_1^2}\int_{\varphi}^{\varphi+2\pi}\sin^2(\omega t-\varphi)\,\mathrm{d}(\omega t) = \frac{R_f}{\omega}\cdot\frac{V_{\max}^2}{Z_1^2}\cdot\pi.$$

The equation $k = w/w_s$ of these two quantities of heat is thus

$$k = \frac{1}{\pi}\int_{\omega t_0}^{\omega t_0+\delta} y_1^2\,\mathrm{d}(\omega t) \quad . \; . \; . \; . \quad (4)$$

By integration we find k as a function of the two quantities t_0 and δ, which we still have available. *Fig. 9* shows $k = \mathrm{f}(\delta)$ for some values of ωt_0 (thin lines); the heavy line is the envelope of the series of curves and shows the greatest value of k that can be reached with a given δ. At first sight it appears that k, though being greater than 1 (maximum about 1.67), does not reach the required minimum value 2, so that apparently the method is inadequate. There is, however, an incidental circumstance that has so far been left out of consideration, namely the fact that the core of the choke is rather highly saturated, not so highly as to cause inconvenience from the drawbacks already mentioned (current strongly distorted and greatly dependent upon the mains voltage), but to such an extent that the starting current impulse reaches much higher values than would follow from the above calculation. We shall not try to include this non-linear effect in the calculation but merely state that, provided t_0 and δ are favourably chosen, it is capable of raising k to the required value of 2.

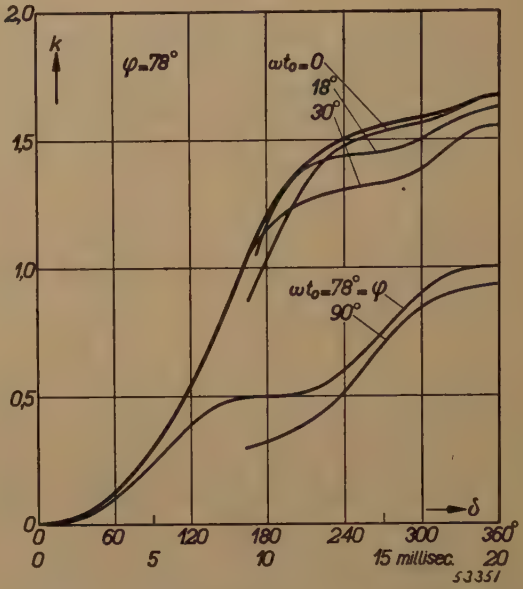

Fig. 9. Light lines: the quantity k of eq. (6) as function of the angle δ, which is proportional to the time during which the contact is closed, for cotan $\varphi = 0.21$ and some values of ωt_0. The heavily drawn envelope indicates the greatest value k which with given δ is obtained with the corresponding optimum value of ωt_0.

The foregoing calculation for a linear self-inductance has by no means become valueless, since in spite of its imperfection it shows how t_0 and δ can best be chosen; it only has to be borne in mind that the actual values of k may be greater than calculated.

From fig. 9 it is seen that, as was to be expected, the curves with increasing δ rise continuously. Therefore δ should preferably approach a full period as closely as possible. It has to be taken into account, however, that it is not practicable to construct a synchronous switch that is closed for practically a whole cycle and opened only for a small fraction of that time. Fig. 9 shows that very little of the greatest possible value of k need be sacrificed to get a much smaller angle δ, say $\delta = 200°$ (corresponding to 11 milliseconds), $k \approx 1.3$. With a further reduction of δ, however, k diminishes rapidly. Fig. 9 further shows that ωt_0 must lie round about 0, but that it is not very critical.

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[4] In fact R_f depends upon temperature, and thus upon time; In a short time such as we are dealing with here (less than 1 cycle) R_f may however be taken as being constant. Even with a hot filament R_f is such a small part of the total resistance R_1 that we can ignore the change taking place in Z_1 and φ_1 while the filament is heating up.

The switching mechanism

The switch as a whole is characterized by the current i_a in the magnet coil at which the armature is just attracted and the contact closed, and by the smaller current i_b at which the armature is just released. By i_a and i_b we mean the momentary values; we shall disregard for a moment the mechanical inertia of the armature itself.

We start from an interval of time during which the contact is still open and the current i_2 in the coil is increasing. As soon as i_2 has reached the value i_a the contact is closed and the coil short-circuited. The current i_2 does not then immediately fall to zero but continues to flow across the contact, decreasing exponentially according to

$$i_2 = i_a \cdot e^{-\frac{R_2}{L_2}t'}, \quad . \; . \; . \; . \; . \; . \; . \quad (5)$$

where R_2 and L_2 are respectively the resistance and the self-inductance of the coil and t' is the time reckoned from the moment at which the contact closes.

As soon as i_2 has dropped to the value i_b the coil releases the armature, and at that moment $\omega t' = \delta$. From (5) it then follows that

$$\delta = \frac{\omega L_2}{R_2} \cdot \ln \frac{i_a}{i_b} \text{ radians} \quad . \; . \; . \; . \; . \quad (6)$$

Here δ is known (see previous paragraph) and ω likewise, so that (6) is an equation which has to be satisfied by L_2, R_2, i_a and i_b.

It has already been said that the frequency f_c of the contact may also be lower than the mains frequency f, say $f_c = 2f/3$. The lower the frequency f_c, the larger the angle δ must be, that is to say the larger (according to (6)) L_2/R_2 must be (it would not help to increase the ratio i_a/i_b because δ is only proportional to the logarithm of this ratio). Any increase of L_2/R_2 however involves larger dimensions of the coil and cannot therefore be considered if one wishes to keep to the desired small dimensions of the switch.

A second equation between some of these quantities follows from the fact that the current i_a which just attracts the armature must be so small that in the stationary state the current reaches this value even at the lowest mains voltage occurring. Assuming that the mains voltage may drop to 20% below the nominal value, and ignoring L_1 with respect to L_2 and R_1 with respect to R_2, then we must have

$$i_a < \frac{0{,}8\ V_{\max}}{\sqrt{\omega^2 L_2^2 + R_2^2}} \quad . \; . \; . \; . \; . \; . \quad (7)$$

Another equation arises from the limit that has to be set for the power P taken up by the coil in the working state (thus when the lamp is ignited). Owing to the desired small dimensions of the starter switch, this power dissipation must be very small (< 1 watt). When the arc voltage of the lamp is indicated by V_b (= about 110 V) then

$$P = \frac{V_b^2}{\omega^2 L_2^2 + R_2^2} \cdot R_2, \leqq 1 \text{ watt}, \quad . \; . \quad (8)$$

The equations (6)-(8) furnish a guide for the designing of the switch. In its ultimate construction the characteristic quantities have the following values:

$L_2 = 28$ H, $\quad i_a = 10$ mA,
$R_2 = 12\,000\ \Omega$, $\quad i_b = 1$ mA.

The equations (7) and (8) are amply satisfied, since according to (7) i_a could amount to as much as 16.7 mA and according to (8) $P \approx 0.7$ watt. According to (6) however $\delta = 1.7$ radians $= 97°$. This calculated value is therefore much smaller than our target, but owing to some circumstances not so far taken into consideration the actual value is rather higher than the calculated value. In addition to the mechanical inertia, which delays both the moment of closing and that of opening, one must take into account the spark arising upon the contact being opened, so that the current is apt to flow longer than has been calculated above. Moreover, to ensure sufficient contact pressure, the armature is resiliently connected to the contact. Consequently when the armature is closed and the current in the coil is diminishing the contact will not open until the armature is released. As a result of all these effects, the actual value of δ becomes more than half a cycle, as is shown by oscillograms. As to the switching-on moment, a closer investigation would become rather lengthy, but oscillograms show it to lie in the neighbourhood of the desired value 0. The value of k corresponding to $t_0 \approx 0$ and $\delta \approx 200°$ is approximately 1.3 according to fig. 9. As already stated, owing to the saturation of the choke, k reaches a much higher value (about 2).

Constructional details

It will already have been noticed that i_a is much greater than i_b, the ratio i_a/i_b being 10. This was necessary to keep the contact closed long enough (see equation (6)). This large ratio of the two currents has been obtained by designing the construction on the lines indicated in *fig. 10*. Here the armature is a small iron pin affixed to a leaf spring, one end of which is clamped while the other end carries the moving pole of the contact. A stop ensures a fairly high tension in the spring in the state of rest. The armature protrudes into an opening in the magnetic circuit. The dimensions are such that the magnetic flux passing through the armature in the closed state is far in excess of that in the state of rest. Consequently i_a is much greater than i_b.

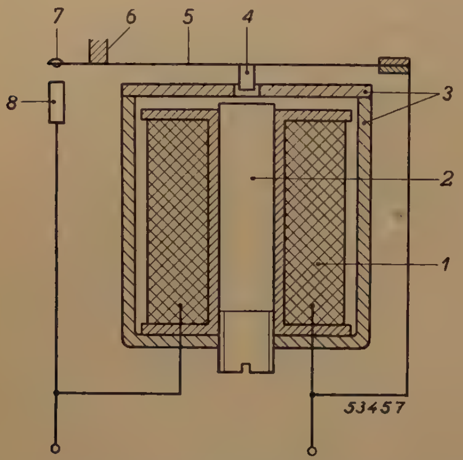

Fig. 10. Enlarged diagrammatic cross-section of the electromagnetic starter switch. *1* = coil, *2* = core, *3* = magnetic circuit, *4* = armature, *5* = leaf spring, *6* = stop, *7* = movable pole of the contact, *8* = fixed pole.

The explanation of this is as follows. Let us suppose that of the flux Φ in the core a part $p_a \cdot \Phi$ passes through the armature in the state of rest and a part $p_b \cdot \Phi$ in the closed state, whereby $p_a \ll p_b$ (say $p_a = 2\%$, $p_b = 20\%$). We assume that the bias in the spring is so great that the spring tension may be regarded as being practically constant, regardless of the position of the armature. Taking Φ_a as the value of Φ corresponding to the current i_a and Φ_b as the value corresponding to i_b, since in both cases the force exercised upon the armature just corresponds to the spring tension, we have by approximation $p_a \Phi_a = p_b \Phi_b$.

Since the flux is approximately proportional to the current passing through the coil, $p_a i_a \approx p_b i_b$, or $i_a/i_b \approx p_b/p_a$, which according to the supposition is large with respect to unity.

The core is partly threaded (fig. 10) so that it can be adjusted to the best position with a screwdriver.

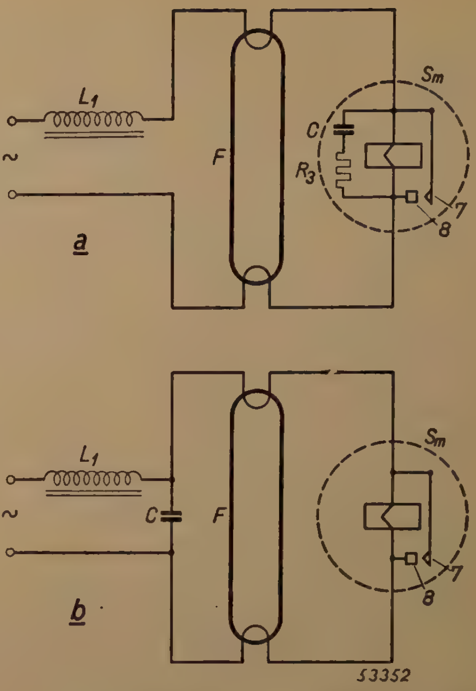

Fig. 11. Two ways of installing an anti-interference capacitor C, *a*) on the starter side of the filaments but in series with a current-limiting resistor R_3, *b*) on the mains side of the filaments, the resistance of the filaments performing the function of R_3. F = fluorescent lamp, L_1 = ballast choke, S_m = starter, *7* and *8* = respectively movable and fixed poles of the contact.

In addition to the switching mechanism proper the starter must contain some other components. First of all there is a capacitor (6000 pF) connected in parallel with the lamp, with the object of suppressing radio interference while the lamp is ignited and to minimize sparking at the contact upon ignition. For the latter purpose it is necessary to have a resistor in series with the capacitor, so as to reduce the discharge current impulse upon the contact being closed. Room has to be found in the starter also for this resistor (R_3 in fig. *11a*), unless the arrangement of fig. 11*b* is adopted, where the filaments take over the current-limiting function of R_3. In that case, however, either the capacitor has to be placed outside the starter or the starter

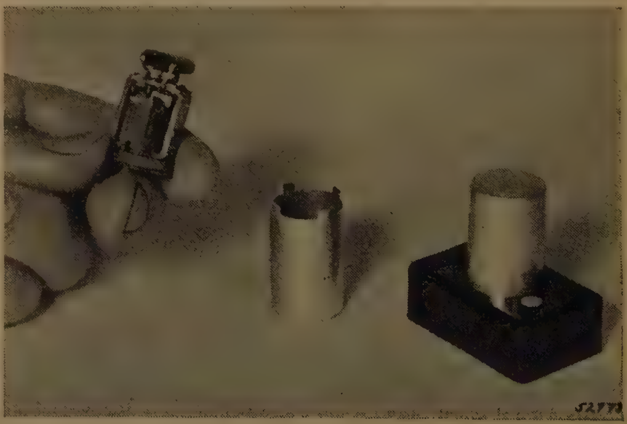

Fig. 12. The new starter switch. On the left opened, on the right placed in a holder.

itself has to be provided with two extra contacts, but then this type of starter would no longer be interchangeable with the glow-discharge bimetallic starter. The solution according to fig. 11*a* has therefore been given preference.

Fig. 12 shows the interior of this starter switch. The external dimensions are: diameter 20 mm, height 34 mm.

Fig. 13 shows how the starters can be mounted in a fixture.

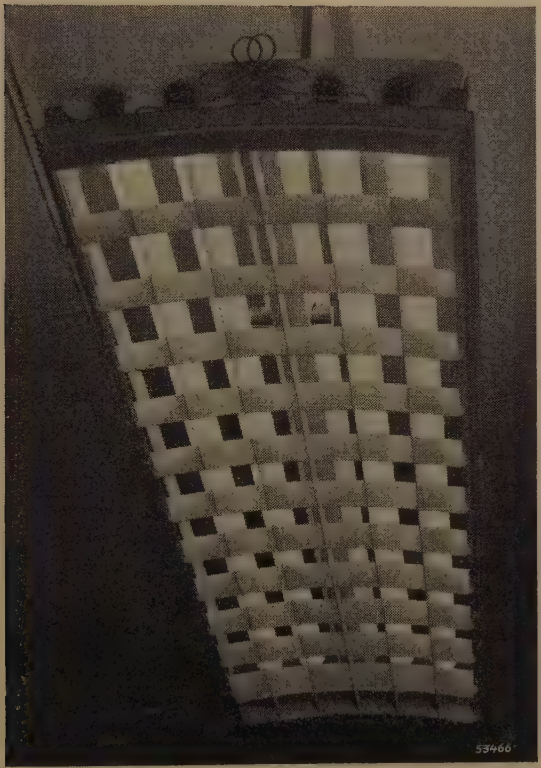

Fig. 13. Fixture (viewed obliquely from underneath) with four TL lamps. In the photo two of the four starters can be seen.

Results

Measurements have shown that under normal conditions the new starter ignites the lamp within 0.3-0.4 sec. An example of this is given in *fig. 14*, which is the oscillogram of the voltage across one of the filaments during the heating and ignition process. In fig. *15a* is the oscillogram of the current in the magnet coil (the exponentially diminishing part is clearly discerned); b is the oscillogram of the voltage peak across the lamp at each interruption.

These voltage peaks, which have an amplitude of about 2000 V, are much greater than the peak voltage at which according to fig. 3 the lamp ignites with cold cathodes (about $360\sqrt{2} \approx 500$ V). From this it is not to be concluded, however, that the starter will ignite the lamp immediately after switching on, which would be entirely in disaccordance with the object. The ignition of the lamp, that is to say the starting of a glow discharge and the changing of that discharge into an arc, requires a much higher voltage when only a weak source of energy is available than is required when that source is a strong one. Fig. 3 only holds when a strong source of energy is used, such as the lighting mains. In the case of the starter, however, there is only the low energy available that is accumulated in the choke, and even the much higher voltage peaks which fig. 15*b* shows as occurring are not sufficient to ignite the lamp with cold cathodes.

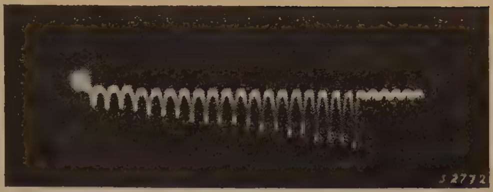

Fig. 14. Oscillogram of the voltage across one of the filaments of a TL 40 W lamp while heating up with the aid of the electromagnetic starter. After 20 cycles (0.4 sec) the lamp is ignited.

From the increase in amplitude of the heating voltage (fig. 14) it is to be deduced that the cathodes have in fact reached the right temperature before the lamp is ignited.

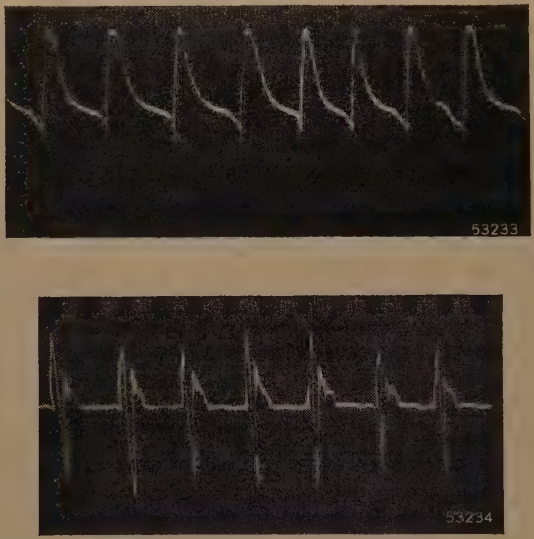

Fig. 15. Oscillogram of *a*) the current i_2 in the magnet coil (the differences in the intervals between the current peaks are due to irregularities in the film transport), *b*) the voltage peaks across the lamp while the cathodes are heating up. The amplitude of the peaks is about 2000 V.

If conditions are highly unfavourable (for instance low ambient temperature) it may take from 0.5 to 1 sec before the lamp ignites, but this is still shorter than the time taken with the older types of starters.

This new starter can be used not only for the 40 W TL lamp but also for the smaller 25 W type of lamp.

THE NEW CANDLE

by W. de GROOT.

535.241.42:535.233

This article is concerned with a circular letter sent out by the "Comité International des Poids et Mesures" bringing the "new candle" into use on the 1st January 1948. The brightness of a black body is calculated in terms of the new candle as a function of the temperature with the aid of Planck's radiation formula (with $c_2 = 14385$ μ °K). For the mechanical equivalent of light the value $M = 683$ new lumen/watt (nlm/W) is found.

Introduction

The "new candle", a unit for measuring luminous intensity, is the subject of an article [1]) which appeared in this journal in 1940, and it was to have been introduced on the 1st January of that year. Owing to the difficulties of international communication at that time its introduction was postponed; on the 1st January 1940 the "Comité International des Poids et Mesures" sent out a circular letter to the various countries asking them to await further advice ("nouvel avis") before changing the units.

It was not until 1947 that a second circular was despatched in which the 1st January 1948 was fixed as the date on which the new unit was to come into force. An unofficial translation of this circular reads as follows:

Concerning changes in photometric units

By virtue of the powers which were conferred on it by the Conférence Générale des Poids et Mesures in 1933, the Comité International, considering the resolution of the 1937 session (Procès-Verbaux du Comité International, 1937, pp. 236 and 64) and taking note of the desire expressed by the Comité Consultatif de Photométrie in 1939 (Procès-Verbaux, 1939, p. P28), with a modification concerning the date of application, decided that the "new candle" would come into force on the 1st January, 1948.

The present resolution constitutes the "further advice" of execution for which the circular of 1st January, 1940, signed by the President and Secretary of the Comité International des Poids et Mesures asked the various countries to wait, before proceeding with any change of unit. The Comité International adopts "résolution 3" unaltered concerning photometric units, submitted to them in 1939 by the Comité Consultatif de Photométrie (Procès-Verbaux, 1939, pp. P32-P35), the text of which is reproduced below:

1. *The present situation*

At the present time, the units of luminous intensity in use in different countries are based on flame standards or on the values assigned to certain electric incandescent lamps maintained in the National Laboratories. France, Great Britain and the U.S.A. agreed in 1939 to adopt a common unit, which was subsequently adopted in certain other countries. Various proposals had been made with a view to establishing a unit which should be based on a primary standard source, that is to say, one reproducible by means of a specification. Nevertheless, it is only in recent years that such a source has been shown to be practicably realised.

2. *The primary standard*

This standard, adopted in principle by the Comité International des Poids et Mesures in 1930 and 1933, is a total radiator (black body), at the freezing point of platinum, and the value of the unit of luminous intensity (adopted in 1937) is such that the brightness of 1 cm^2 of the standard is 60 units. The form in which the standard is actually realised is, in its essentials, that which was conceived by the National Bureau of Standards at Washington and which is described in the Procès Verbaux du Comité International des Poids et Mesures, 1931 (p. 249). The colour of the light furnished by this standard does not differ sensibly from that emitted by the flame standards and the incandescent lamp standards referred to in paragraph 1.

3. *Measurement of light sources having colour temperatures different from that of the primary standard*

Modern light sources (even if one excepts those which are markedly coloured) have colour temperatures considerably higher than that of the primary standard, and it is consequently necessary to define the following procedure by which these sources are to be evaluated. The method approved by the Comité International des Poids et Mesures in 1937 consists in using a procedure which is based on the relative luminosity curve adopted by this Committee; e.g. a coloured filter is used which, placed between the primary standard and the photometer, gives a colour comparable with that of the light to be measured. The transmission factor of this filter is determined from its spectral transmission curve by means of the relative luminosity curve adopted in 1933 by the Comité International des Poids et Mesures (Procès-Verbaux, 1933, p. 62).

4. *Definition of the units*

The photometric units may be defined as follows:

I. The new candle (unit of luminous intensity). — The magnitude of the new candle is such that the brightness of a total radiator at the freezing point of platinum is 60 new candles per cm.^{2}

II. The new lumen (unit of luminous flux). — The new lumen is the luminous flux emitted in unit solid angle (1 steradian) by an uniform point source having a luminous intensity of one new candle.

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1) G. Heller, The new luminous standard, Philips Techn. Rev. 5. 1-5, 1940.

5. *The Practical realisation of the units.*

While it should be possible to realise the primary standard at any time and in all laboratories possessing the necessary apparatus, in the majority of practical applications the reference standards will remain the secondary standard carbon or tungsten filament lamps, the luminous intensities of which will have been determined by reference to the primary standard. The precision of comparisons of these lamps between themselves is higher than the precision with which the primary standard can in practice be reproduced. Secondary standard lamps of this type will be maintained in the various National Laboratories and at the Bureau International des Poids et Mesures. Values attributed to these secondary standards with reference to the primary standard will be determined either by direct comparisons in one or more of the principal National Laboratories or indirectly by inter-comparison with other similar lamps whose values have been determined by direct comparison. Thus, the values assigned to the secondary standards maintained at the Bureau International and in each of the National Laboratories will be expressed in terms of the mean unit, which will itself be determined as the average of the results of all the laboratories, in which the primary standard will have been realised.

An analogous procedure will be used in case of lamps having colour temperatures higher that than of the primary standard, just as in the derivation of the lumen from the candle.

The brightness ("luminance") of a black body as a function of temperature

Since the new light unit is defined in terms of the brightness ("luminance") of the radiation from a black body at a prescribed temperature, it is obvious that we should know how this brightness ("luminance") varies as a function of the temperature.

We shall start from the conventional standpoint that the luminous intensity of a light source is determined with the aid of the international relative luminosity curve $V(\lambda)$, which reaches its maximum value (= 1) at the wavelength $\lambda = 0.555$ μ. Let $E(\lambda, T)\, d\lambda$ (measured in watts per cm²) be the energy irradiated in the hemisphere, in the wavelength range λ, $\lambda + d\lambda$,per cm² of a black body of the absolute temperature T. This amounts to $M \cdot E(\lambda, T)\, V(\lambda)\, d\lambda$ lumen, where the constant factor M — thus defined — represents the so-called mechanical equivalent of the light.

By integration over all wavelengths of the visible spectrum one finds the total luminous flux emitted by 1 cm² in lumen:

$$\Phi = M \int_{0{,}38\,\mu}^{0{,}78\,\mu} E(\lambda, T)\, V(\lambda)\, d\lambda \quad . \; . \; . \quad (1)$$

According to Lambert's law the luminous intensity in the direction perpendicular to the respective plane of 1 cm², which is nothing else than the brightness ("luminance") B, is equal to $(1/\pi) \times$ the luminous flux, so that

$$B = \frac{\Phi}{\pi} = \frac{M}{\pi} \int E(\lambda, T)\, V(\lambda)\, d\lambda \quad . \; . \quad (2)$$

The determination of the new candle implies that for $T = T_{Pt}$, the freezing temperature of platinum, B must equal 60, so that

$$60 = \frac{M}{\pi} \int E(\lambda, T_{Pt})\, V(\lambda)\, d\lambda \quad . \; . \quad (2a)$$

Eliminating M from (2) and (2a) by division, one arrives at

$$B = 60\, \frac{\int E(\lambda, T)\, V(\lambda)\, d\lambda}{\int E(\lambda, T_{Pt})\, V(\lambda)\, d\lambda} \quad . \; . \; . \quad (3)$$

From this one can determine B by calculating $E(\lambda T)$ with the aid of Planck's formula

$$E(\lambda, T) = c_1 \frac{\lambda^{-5}}{e^{c_2/\lambda T} - 1}, \quad . \; . \; . \quad (4)$$

and substituting the value of T_{Pt}.

If $c_2/\lambda T > 7$ for all wavelengths of the visible spectrum, the denominator is equal to exp $(c_2/\lambda T)$ to a sufficient degree of accuracy (0.1%), so that formula (4) may be replaced by what is known as Wien's formula:

$$E(\lambda, T) = c_1\, \lambda^{-5}\, e^{-c_2/\lambda T} \quad . \; . \; . \; . \; . \; . \quad (4a)$$

This is the case for $T < 3000$ °K ($\lambda \leqq 0.7 \mu$), whilst if one is satisfied with an error of 1% in the middle of the spectrum ($\lambda = 0.6\ \mu$) formula (4a) can even be used up to $T \approx 5000$ °K.

Now the values of c_1 and c_2 are more or less uncertain[2]). As regards c_1, this does not give rise to any difficulty because this factor does not occur in equation (3), but the expression does depend on the value of c_2. In this article we shall put

$$c_2 = 14385\ \mu\ °\mathrm{K},$$

in agreement with the theoretical value $c_2 = c\, h/k$, (c = velocity of light, h = Planck's constant, k = Boltzmann's constant), which has been given by Dumont and Cohen[3]), viz. 14384.7 ± 1.9.

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[2]) See for instance H. T. Wensel, The international temperature scale and some related physical constants, J. Res. Nat. Bur. Stand. **22**, 375-395, 1939 and [3]).

[3]) J. W. M. Dumont and C. R. Cohen, Our knowledge of the atomic constants F, N, m and h in 1947 and of other constants derivable therefrom. Rev. mod. Phys. **20**, 82-108, 1948 (No. 1); see also R. T. Birge, New table of values of the general physical constants (as of August 1941), Rev. Mod. Phys. **13**, 233-239, 1941 and Rep. Progress Phys. London **7**, 126-134, 1941.

Equation (3) depends upon the value of c_2 not only explicitly but also implicitly, since the value that has to be ascribed to T_{Pt} is likewise dependent on c_2 (2041.7 °K for $c_2 = 14385$).

In connection with the freezing point of platinum, it must be noted that temperatures above 1336 °K are usually determined by comparing the radiation of a black body monochromatically with that of a black body at the temperature of melting gold. The latter temperature is exactly known ($T_{\mathrm{Au}} = 1336$ °K) because it can be measured with a gas thermometer. The temperature required then has to be derived from the measured ratio of radiations with the aid of Planck's (or Wien's) formula, taking a certain value of c_2 (the international temperature scale of 1931 prescribes $c_2 = 14320$ μ °K).

Using Wien's formula it then follows that

$$\frac{1}{T_{\mathrm{Au}}} - \frac{1}{T} = \frac{\lambda}{c_2} \ln R, \quad \ldots\ldots\ldots \quad (5)$$

where R represents the monochromatic ratio of radiations referred to. If the unknown temperature T could be measured in some other way, for instance also with the gas thermometer, then we should have a means of determining c_2. Van Dusen and Dahl 4) have recently done this for the melting points of Ni and Co, employing the gasthermometrical determinations of Day and Sosman obtained with the same samples of metal. They found $c_2 = 14382 \pm 6$ μ °K, which agrees with the "theoretical" value 14385, whilst at the same time it proves that the value of 14320 adopted in the international temperature scale is too low.

For the freezing point of platinum, which cannot be measured with a gas thermometer, one finds

$$R = R_0 = 299{,}0 \quad \text{for} \quad \lambda = \lambda_0 = 6528 \text{ Å} = 0{,}6528\ \mu.$$

From formula (5) it therefore follows that for T_{Pt}

$$\frac{1}{T_{\mathrm{Au}}} - \frac{1}{T_{\mathrm{Pt}}} = \frac{\lambda_0 \ln R_0}{c_2} = \frac{3{,}72125}{c_2}.$$

Introducing these values of T_{Pt} and c_2 in equation (3) we find for B as a function of T the figures given in *table I*. The dependence of B on T as graphically represented in *fig. 1* can be expressed, approximately, by the formula

$$\log B = 7{,}224^5 - 11{,}437\left(\frac{1000}{T}\right) + 0{,}648\left(\frac{1000}{T}\right)^2, \quad (6)$$

which holds for $T = 1000$ °K up to $T \approx 5000$ °K5).

Table I. The brightness ("luminance") B of a total radiator (black body) (in new c/cm²) as function of the absolute temperature T for $c_2 = 14385$ μ °K and $T_{\mathrm{Pt}} = 2041.7$ °K.

T (°K)	B (T) (nc/cm²)
1000	0.000273
1200	0.0139
1400	0.243
1600	2.14
1800	11.76
2000	46.5
2041.7	**60**
2200	145
2400	373
2600	835
2800	1670
3000	3050
3500	10220
4000	25500
4500	51900
5000	91800

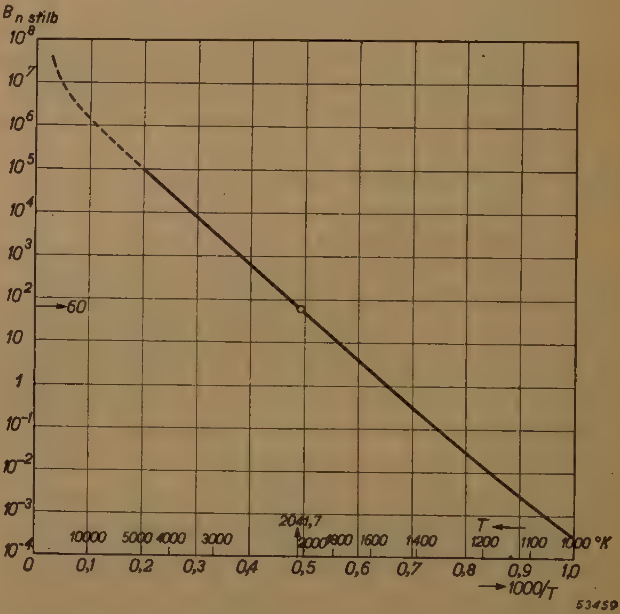

Fig. 1. Graphical representation of the brightness (luminance) B of a total radiator (black body) as function of the absolute temperature T, plotted from the values given in table I.

For $T > 5000$ °K, B increases with T more rapidly than is indicated by (6). It can be shown that for $T \to \infty$ log B approaches (const. + log T), whilst for $T = \infty$ log formula (6) would give $B = 7.2245$.

The mechanical equivalent of light

To calculate the mechanical equivalent of light M one can use equation (2a) in combination with (4) or (4a). It is seen that M is likewise dependent on the value of c_2, but it also depends on the value of c_1. The following equation can be deduced for the effect of these two quantities upon M

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4) M. S. van Dusen and A. I. Dahl, J. Res. Nat. Bur. Stand **39**, 291-295, 1947 (No. 3).

5) The fact that an equation of this shape must apply, at least as regards the first two terms, can be deduced from the fact that monochromatically, according to Wien's formula, the radiation and thus also the brightness ("luminance") are proportional to exp. ($-c_2/\lambda T$). Since the wavelenght range of visible light can be regarded as a rather narrow band round about the wavelength $\lambda = 0.555$ μ, it follows that

$$\ln B = A - B/T,$$

where A is a constant and $B \approx c_2/0.555$. This formula has already been given by Nernst; seen also W. Geiss, Das Licht, **13**, 19-36, 1943 and E. F. Caldin, Proc. Phys. Soc. London **57**, 440-443, 1945.

$$\frac{\mathrm{d}M}{M} = -\frac{\mathrm{d}c_1}{c_1} + \frac{\mathrm{d}c_2}{775}, \quad {}^{6)}$$

where c_2 is expressed in μ °K.

In the calculation of M, substituting for c_1 the value recommended by Birge (1941)

$$c_1 = 3{,}7403 \cdot 10^4\ W\mu^4/\mathrm{cm}^2$$

and taking for c_2 the value

$$c_2 = 14385\ \mu\ {}^\circ\mathrm{K},$$

we find $M = 683$ new lumen/watt 7)).

It would be highly desirable to compare this value with a direct experimental determination of the quantity M, but the literature on the subject gives only scanty data. In most cases calculated values are given (with different values for c_1 and c_2 and a different light unit). M may for instance be determined directly by measuring on the one hand the luminous intensity of the light source and on the other hand the spectral energy distribution in absolute units. This has been done by Krefft and Pirani 8)), among others, using a sodium lamp; the value found by them is $M = 694 \pm 15$ Hefner-lumen/watt $= 640 \pm 15$ new lumen/watt. The difference compared with the calculated value, 683 nlm/W, is thus rather considerable. It is desirable that similar measurements should be repeated, bearing in mind, however, that in practice the relative luminosity curve of any observer never corresponds precisely to the international relative luminosity curve V (λ). The observers will therefore have to be very carefully selected and preferably a large number of observers should participate.

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6) The number 775 is the value of the product $\lambda_c \cdot T_{\mathrm{Au}}$, where T_{Au} is the melting point of gold = 1336 °K and λ_c the so-called Crova wavelength at the freezing temperature of platinum, viz. $\lambda_c = \int \lambda E\,(\lambda,\ T_{\mathrm{Pt}})\ d\lambda / \int E\ (\lambda,\ T_{\mathrm{Pt}})\, d\lambda = 0{,}58\ \mu$.

7) When calculating M with the value of c_2 which has been taken in the international temperature scale, namely $c_2 = 14320\ \mu\ {}^\circ\mathrm{K}$, and with $c_1 = 3.7403 \cdot 10^{-16}\ \mathrm{W} \cdot \mathrm{m}^2$, we find $M = 627$ nlm/W. See also E. F. Caldin, Proc. Phys. Soc. London **58**, 207-210, 1946.

8) H. Krefft and M. Pirani, Z. techn. Phys. **13**, 367-369, 1932.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk can be obtained free of charge upon application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Netherlands.

1719a: M. Gevers en F. K. du Pré: Power factor and temperature coefficient of solid (amorphous) dielectrics (Trans. Faraday Soc. 42A, 47-53, 1946).

For the contents of this paper, see Philips Techn. Rev. 9, 91-96, 1947, No. 3 and these abstracts, No. **1726.**

The subject contained in this paper has been dealt with extensively in Philips Res. Rep. 1, 197-224, 279-313, 361-379, 447-463, 1946.

1763: P. Bayens: The effect of operating conditions on the throwing power of cyanide cadmium plating solutions (Third Int. Conf. on Electrodeposition, No. 13).

Bright cadmium electrodeposits may be formed under widely different conditions, but for economic working, i.e. for high throwing power, with a given composition of the solutions there are narrow limits of temperature and current density. These limits are studied experimentally.

1771: C. J. Bouwkamp:Concerning a new transcendent, its tabulation and application in antenna theory (Quart, appl. Math. 4, 394-402, 1948).

The author discusses a new function E_1 (z) which is related to the integral sine and cosine functions in the same way as the latter are to the ordinary sine and cosine functions. Numerical evaluation is accomplished by power-series expansion (z small) and asymptotic expansion (z large). The gap is bridged by a Taylor-series method (z moderate). A six-decimal table covering the range $z = 0(0.2)20$ is included. Application of the new function to Hallén's antenna problem is indicated. Additional tables of antenna functions are given.

1772*: F. A. Kröger: Some aspects of the luminescence of solids (310 p. 72 figs., 27 tables Elsevier Publ. Cy, Inc., Amsterdam, New York, London, Brussels, 1948.

This book is a monograph, based on experimental work on luminophors, carried out in the Philips Research Laboratory at Eindhoven 1940-1945. It does not pretend to give a complete representation of the present knowledge regarding the phenomenon of luminescence in solids, nor does it give a general survey. It contains some hitherto unpublished experimental results together with theoretical considerations regarding certain aspects of this field of science. In chapter I a brief consideration is given to the energy levels of pure and disturbed crystals. Starting from the energy diagram it is shown that different types of luminescent effects must exist. Emissions of activated luminophors reported in literature have been tabulated and classified according to the diagram. Further attention has been paid to the different mechanisms of the excitation process and its most important attendant phenomenon.

Four further chapters are devoted to new experimental results concerning some particular systems, viz.: tungstates, molybdates and luminophors activated by manganese, uranium and titanium. For manganese the activating properties of the tetravalent ion have been discovered, beside those of the divalent ion already known.

In the sixth and final chapter the influence of temperature on the efficiency of luminescence has been considered both from the experimental and from the theoretical angle.

1773*: W. Elenbaas: Dissipation of heat by free convection (De Ingenieur **60**, 021-034, 1948, No. 7).

A body differing in temperature from the surroundings loses energy not only by radiation but also by conduction and convection. The general laws governing this latter dissipation of heat are investigated. The many quantities governing this transfer may be combined into a few dimensionless numbers by means of similarity considerations. This leads to an important simplification and facilitates the survey of experimental and theoretical results. The above mentioned considerations are first applied to bodies which may be characterized by one linear dimension only (the vertical plate, the horizontal cylinder, the sphere), and next to bodies characterized by two such quantities (the vertical cylinder of finite height, cooling ribs, the inner surface of vertical tubes).

This paper appears in full in Philips Res. Rep.

1774*: J. M. **Stevels**: Progress in the theory of the physical properties of glass (104 p., 26 figs., 22 + 5 tables, Elsevier Publishing Cy., Inc., Amsterdam, New York, London, Brussels, 1948.

Starting from the fruitful ideas of Zachariasen and their experimental affirmation by Warren and his coworkers, it was possible to get a much better and detailed knowledge of the structure of glass, and such properties as density, electric conductivity, dielectric losses and refraction.

In chapter I a survey is given of the knowledge of the structure of glass as far as it may be considered generally accepted.

Chapter II deals with the density of glass. With the aid of a new density relation, the physical background of which is amply discussed, various interesting conclusions are drawn about the structure of a number of glasses (especially of the borate glasses).

In Chapters III and IV the electric conductivity and the dielectric losses of glass are discussed. The general picture of the behaviour of the metallic ions, which jump from interstice to interstice in the network, is worked out extensively. This theory leads to a number of quantitative relations which are adequately checked experimentally.

In Chapter V a theory of the molecular refraction is given, based on the new conceptions.

Finally, in a number of appendices all the glasses mentioned in the book are listed comprehensively.

1775: K. **ter Haar** and W. **Westerveld**: The colorimetric determination of nickel as $Ni_{(4)}$ dimethylglyoxime (Rec. trav. Chim. Pays Bas, **67**, 71-81, 1948).

A description is given of a colorimetric determination of nickel as $Ni_{(4)}$ dimethylglyoxime, but in contrast to the customary methods, use is made of persulphate as oxidizing agent. The influence of other metallic ions has been investigated too.

It appears that, of the elements investigated Ag must be removed, while the alkaline earth metals give a sulphate precipitate which can be removed by centrifuging. The determination of Ni in the presence of Mn, Fe, Cu and Co presents the greatest difficulties. In many cases the writhers have succeeded finally in determining nickel in the presence of these elements without removing them. Thus it is possible to determine accurately 5% Ni and over in manganese, 0.25% and over in iron, 0.05% and over in copper and 0.05% and over in cobalt.

In general it has been established that the highest accuracy is obtained when full attention is paid to the following points:

1) the avoidance of ammonia
2) the regulation of the amount of dimethylglyoxime.
3) the acidity of solution.

If one of these points is not in order, the degree of accuracy becomes less. This is the case in the determination of Ni in the presence of cobalt and copper, where the presence of ammonia is a necessary condition for the formation of the colour.

It can be remarked that this method is extensively applied in the Philips Laboratory in the determination of Ni in chrome-iron, Mo and W compounds.

1776: C. **Zwikker**: Systematic relations existing between the properties of solid materials (Physica **14**, 35-47, 1948, No. 1).

When describing the properties of solids it is necessary to distinguish between "generalized forces" or intensity parameters (*i*) and "generalized displacements" or extensive parameters (*e*). The numerical factors occuring in the linear equations expressing the d*e* as functions of the d*i* are called by the author coefficients and those determining the d*i* as function of the d*e*, moduli.

Between the different moduli there exist systematic relations and likewise between the different coefficients. The relations are expanded to the quadratic effects. Care should be taken to distinguish between a modulus and the corresponding reciprocal coefficient.

The theory is extended to include systematic relations between "resistances" and "conductivities", of which relations examples are given too.

1777: F. A. **Kröger**, W. **Hoogenstraten**, M. **Bottema** and Th. P. J. **Botden**: The influence of temperature quenching on the decay of fluorescence (Physica **14**, 81-86, 1948, No. 43).

Temperature quenching causes a marked increase of the rate of decay of fluorescence. It is shown that both the efficiency of fluorescence and the decay are determined by the probabilities of the fluorescence transition and of a radiationsless transition. By combining data from measurements of the efficiency and the decay, it is possible to obtain the two transition probabilities separately, and both as a function of the temperature. The results with $(NH_4)_3UO_2F_5$ and Mg $_2TiO_4$. Mn^{4+} have been used to verify whether the raditionless process follows the theories of **Mott** and **Seitz**, or that of **Möglich** and **Rompe**; they are found to favour the former. A few examples are dealt with.

1778: B. D. H. **Tellegen**: Zijn er naast capaciteiten, weerstanden, zelfinducties nog andere soortgelijke grootheden denkbaar? (T. Ned. Radiogen. **13**, 73-98, Nr 3) in Dutch

The contents of this article are covered by those of Philips Res. Rep. 3, 81-101, 1948, No. 2 (see these abstracts **R** 73).

1779: C. **Zwikker**: Vectorial theory of gear wheel tooth profiles (Appl. Sci. Res. **A 1**, 139-150, 1948, Nr. 2).

The mechanical problem of the admissible gear tooth profiles is dealt with by a method using the geometry of the complex plane. This method is better known in the electrical branch of technical science, but may — as is shown in this paper — easily be generalized to a complete version of plane geometry and applied to mechanical problems.

1780: H. C. **Hamaker**: Current distribution in triodes neglecting space charge and initial velocities (Appl. Sci. Res. **B 1**, 77-104, 1948, Nr. 2).

A theory of the current distribution in triodes with positive grid is developed on the assumption that space charge and the initial velocities of both primary and secondary electrons may be neglected. This theory, which is originally due to **De Lussanet de la Sablonière**, has been put in a more lucid form, and a graphical method has been developed to check the applicability of this theory to any set of observations. From the graphs used for this purpose the different distribution functions which enter the equations can be read off in a very simple manner. In some cases theory and experiment are in excellent agreement; discrepancies occuring in other cases are discussed. In connection with these observations the basic assumptions underlying the theory are subjected to a closer scrutiny.

1781: A. **van der Ziel**: The virtual cathode problem for cylindrical electrodes (Appl. sci. Res. **B 1**, 105-118, 1948, Nr. 2).

After a general discussion on the influence of space charge upon the potential distribution between parallel electrodes, the case of coaxial cylindrical electrodes is investigated. The resultant current-voltage characteristics are calculated and it is shown that the curves obtained are similar to those of the wellknown case of plane electrodes. The theory may be useful for the development of cylindrical tetrodes and pentodes, especially for transmitting valves.

1782: N. **Warmoltz**: A powerful light source for the illumination of Wilson cloud chambers (Appl. sci. Res. **B 1**, 139-142, 1948, No. 2).

A capillary flash tube for the photography of the tracks in a Wilson cloud chamber is described. At an energy input of 500 watt. sec per flash with a choke of 10 mH in series with the flashtube the light output amounts to 15 000 lumen·sec per flash. At a rate of 8 flashes per minute the lifetime of the tube exceeds 1,000,000 flashes at the energy stated above. At about 320 watt·sec the light output is ample sufficient for photographing cloud chamber tracks.